VOL. 76 DECEMBER 1953

TRANSACTIONS OF THE ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

ADELAIDE

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KINTORE AVENUE, ADELAIDE

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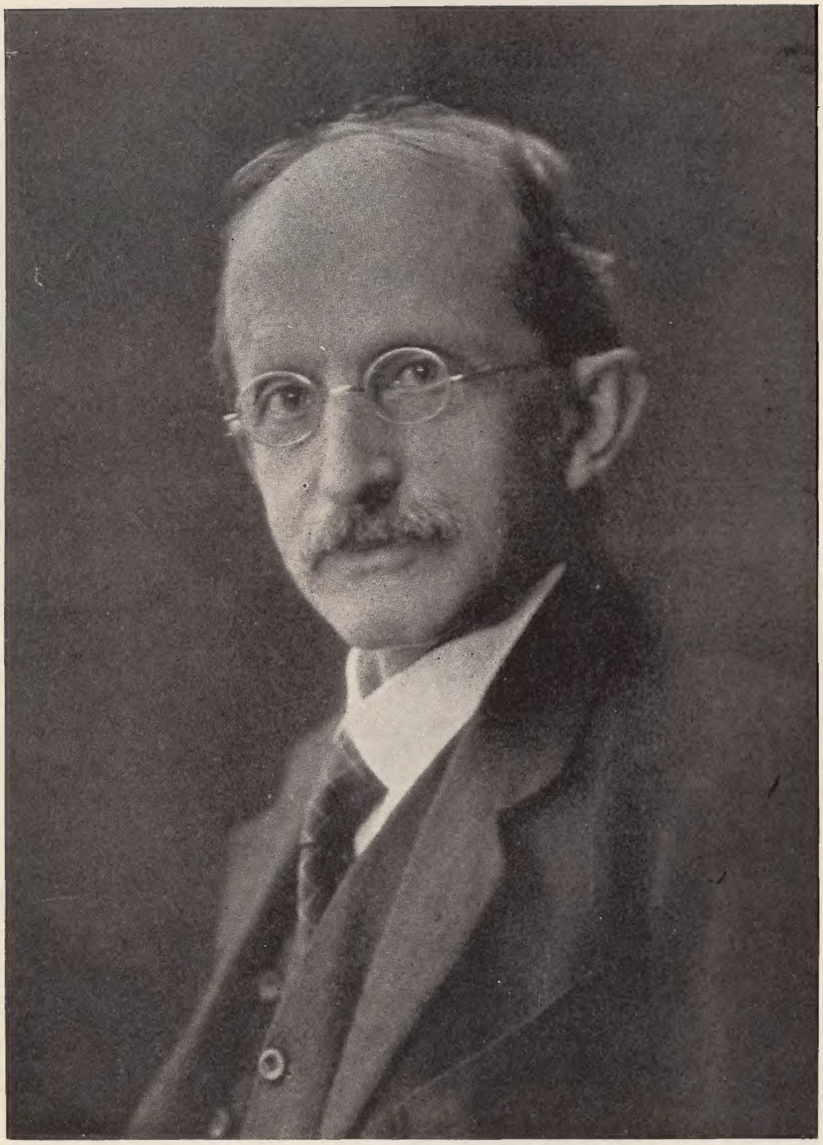

John McConnell Black, A.L.S., 1855-1951

OBITUARY

JOHN McCONNELL BLACK, A.L.S.
(1855 - 1951)

By C. M. Eardley *

John McConnell Black, after working at the last page of the Second Edition of Part III of his Flora of South Australia, retired to bed in the late evening of Saturday, 1 December 1951, leaving open on his table various floras that he had been consulting over the genus *Statice* (*Limonium*). He rose late on Sunday morning, and sat on the verandah; getting up hurriedly, he apparently felt faint, stumbled and died in a few minutes. In spite of his great age of ninety-six, his mind had remained alert and active to the end, and death came after a short illness from which he had almost recovered.

Black was born at Wigtown in south-west Scotland, on 28 April 1855, just after the Crimean War; his father, George C. Black, was Procurator-Fiscal and bank manager there and had three other children. He received his education at the Wigtown Grammar School and then at the Edinburgh Academy, followed by Taunton College School in England, the training ground of other natural scientists, and finally at the commercial "Handels-schule" in Dresden. After spending a period in two banks (in Edinburgh and London respectively), he came to South Australia in 1877 at the age of twenty-two, and farmed at Baroota for five years; there he married Alice Denford of Wellington, South Australia. Farming at that time in the dry Port Pirie district was not successful, and Black with his literary tastes turned to journalism; he moved to Adelaide in 1882, where he made his home for the rest of his life. He joined the staff of the "Register" Newspaper in 1883, but after one or two years he transferred to the "Advertiser" and eventually became Senior Reporter. His colleagues in the Press had the greatest respect and use for his wide knowledge, especially in matters of history, geography and languages. He was a capable and efficient reporter and could handle the most varied assignments, including interviews with French and German visitors in their own languages; he regularly reported the meetings of a German Club, the Allgemeiner Deutscher Verein, where the proceedings were conducted in German. It was in these days, too, that he pursued the study of Arabic with an Afghan accountant.

Sometimes he had to report concerts and theatres; the songs of the Savoy Operas ran in his head a good deal, no doubt because of his sister's connection with them. One of his most spectacular assignments must have been the reporting of the reception at Government House to the first Governor-General, the Marquis of Linlithgow, when he visited Adelaide at about the time the first Federal Parliament met. Occasionally Black wrote leading articles for the "Advertiser." He was also on the official Hansard staff at the meeting of the South Australian House of Assembly in 1884 or 1885, and he remained on it until 1903. During these

* I am indebted for substantial help in writing this account to Professor J. B. Cleland, who prepared the list of species published by Black, to Mr. John Sincock for information about his "Advertiser" period, and to his son, Dr. E. Couper Black.

C. M. E.

days, he was already indulging his botanical interests; he and his wife were keen cyclists and he made extensive tours in the South-East; his connection with the Field Naturalists' Section of the Royal Society also began early.

After his retirement from active newspaper work in 1902, he devoted himself almost entirely to botany, but he did keep in touch with some of his former colleagues and occasionally gave them help in fields where they had learnt to value his capacity; in this way he used to help his friend, J. Sincock, in editing the South Australian Journal of Agriculture about the 1907 period; he also took over the reporting of certain Commissions as casual work after 1903.

A legacy left him by his sister Helen, who was Mrs. D'Oyley Carte of Gilbert and Sullivan fame, enabled him to retire in 1902 at the age of forty-seven. Few legacies have been better bestowed, for it enabled Black to devote himself to the interests that particularly appealed to him, botany and linguistics, and was thus responsible for the production of the most important systematic botanical work in Australia since the days of Bentham, von Mueller and F. M. Bailey—his "Flora of South Australia."

In 1903 Black made a tour abroad to the countries of Great Britain, Europe and South America; one can imagine his delight at travelling in foreign parts—Spain, Italy, France, and Germany—whose languages he had been studying.

On his return, botanical work started in earnest; by 1909 he published "The Naturalised Flora of South Australia," copiously illustrated with drawings by himself and containing 368 species. In the same year he contributed the first of a long series of papers, later entitled "Additions to the Flora of South Australia," to Vol. 33, of the Transactions of this Society; of this series, the last, No. 45, appeared in 1949 (Vol. 73); his current miscellaneous notes and descriptions of new species were published here, so they are important adjuncts to "The Flora." A few new species were included in Part III, Ed. 2, of this work which had not yet been validly published in Latin in accordance with the International Rules of Botanical Nomenclature, so it will still be necessary to publish these Latin descriptions which will appear as "Additions No. 46" in these Transactions. Apart from the "Additions," he published several other botanical papers in the Transactions and in the "South Australian Naturalist," some jointly; the titles appear in the bibliography at the end of this notice. Being a capable linguist—he knew Latin, French, German, Italian, Spanish and some Russian and Arabic—he naturally welcomed any opportunity to study the languages of our aboriginals and was the first to use the International Phonetic Script to record them; his papers on this subject are also included in the bibliography.

In 1920, the South Australian Branch of the British Science Guild (the Guild is now merged in the British Association for the Advancement of Science) asked Black whether he would prepare a "Flora of South Australia" as the first of a series of Handbooks on the Fauna and Flora of this State. The genesis of these Handbooks has been detailed elsewhere; here it will only be mentioned that the author of each Handbook presented his work as a gift to the State, and the Government on its part undertook the publication and sold the works at cost price, with further concessions to students. Black agreed to prepare this Handbook, and set to work steadily, the four successive parts being published in 1922, 1924, 1926 and 1929 respectively by the Government Printer, Adelaide. The new "Flora" was very well done and replaced Ralph Tate's smaller "Handbook of the Flora of Extra-tropical South Australia," Adelaide, 1890. Black's book ran to 746 pages with descriptions and distribution records of 2,430 species, both native and naturalised, and some 400 illustrations by the author; it was well indexed, the descriptions and keys to families, genera and species were good and there were also a useful introduction on the history of botany in South Aus-

tralia, a glossary, and a map of the State. This was the work that South Australian botanists had so long desired; it proved also to fill a gap in the adjacent Australian States, none of which had very recent floras, and those which had been published were for the most part almost unprocurable. There had been nothing as good for the Flora of the Australian mainland since Bentham's "Flora Australiensis" and F. M. Bailey's "Flora of Queensland." The great Ferdinand von Mueller, of course, was co-author of the "Flora Australiensis," and he wrote numerous most valuable monographs and other botanical works on Australian plants; his comparable "Key to the System of Victorian Plants," 1885-8, is excellent in so many ways, yet in this field of a regional flora it is our opinion that Black achieved a better synthesis, he certainly had the advantage of following after the pioneers.

South Australia is contiguous with some part of all the other States except Tasmania, and the general usefulness of Black's Flora in Australia is partly due to this fact; it covers very well the arid vegetation types so widespread over the large central area of the continent and extending into all States.

Black's material for this "Flora" was chiefly his own quite comprehensive South Australian Herbarium and the other Adelaide collections, firstly that of the University, containing especially the plants which Professor Ralph Tate had amassed, those of O. E. Menzel, and of the Elder and Horn and other Expeditions, together with much interstate material, including that of J. B. Cleland from New South Wales and E. Pritzel from Western Australia, together with exotic plants; secondly, the Botanic Garden collection built up by Dr. Richard Schomburgk when he was Director during the last quarter of the nineteenth century (amalgamated with the University collection in 1940); and then there was Professor J. B. Cleland's large private collection. Dr. R. S. Rogers, the orchidologist, wrote the section on Orchidaceae for Black's Flora. There was also close correspondence with the herbaria in other States, especially with Melbourne and Sydney, and of course with Kew in England and others abroad; but it is remarkable that Black did so well, having spent so little time at the large herbaria and botanical libraries; his library facilities were those of the city of Adelaide and its scientific institutions, his own small one and books he could borrow; this left something to be desired in the direction of specialized and current taxonomic literature, though he was always at pains to procure monographs important to him. Black studied and adhered to the International Rules of Botanical Nomenclature carefully, but he was not an obtrusive nomenclaturist. It is perhaps somewhat to be regretted that he did not see more type specimens, though such studies belong rather to the province of a monograph than a flora.

Something more must be said about Black's own Herbarium. It had been collected partly on his trips in earlier years (he was sixty-five before he began writing the "Flora of South Australia") in the regions of Eyre Peninsula, Ooldea, Marree, the North-east, the South-East and less distant regions; his family and botanical friends collected for him too, especially his sons, his son-in-law H. W. Andrew, H. Griffith, E. H. Ising, Captain S. A. White, Professor J. B. Cleland and many others, the last-named a most experienced and critical collector who contributed many new species. Unusual plants naturally found their way to Black because, though never a professional, he was far and away the best systematic botanist in South Australia for over forty years, and State officers and botanists alike consulted him a good deal. Very often he examined and named large collections made by others in distant or interesting parts of the State; many of these were reported upon by him in the Transactions of this Society (see bibliography), and duplicates from such specimens would usually be available to him for his own collection; there are surprisingly few

of the total of South Australian species not represented in it. The Herbarium was very compactly arranged and kept in Black's own study; it was always in use, in fact it formed an integral part of his daily life. All the specimens are accompanied by drawings and notes made at every dissection, Black never failed to note his observations. Apparently he delighted in these sketches and drawings, which were excellent botanically and often very pleasing and perhaps coloured; they are to be found all over the margins of many of his personal botanical books. The Herbarium, then, represents all this academic work together with the labour of labelling, mounting and poisoning the specimens; he accepted such routine tasks as a matter of course, but he did get help with the very exacting proof-reading of his books, especially from Professor J. B. Cleland and Miss M. Raymont, and with the compilation of the Index from J. F. Bailey. He offered the Herbarium, in advance, as a gift to the University of Adelaide at his death; the offer was couched in characteristically modest language, and the Herbarium is now in the Botany School of the University.

The Second Edition of the "Flora of South Australia" was undertaken with the same Government help as the first, and with a generous grant from the Commonwealth Science and Industry Endowment Fund for the preparation of illustrations, thus approximately half the number of species is illustrated in the Second Edition. Black himself had drawn all except the Orchid illustrations (by Miss R. C. Fiveash) in the First Edition; his new artists were Miss Maude Priest, Miss Gwen Walsh and Miss Mabel Raymont. Black's only remuneration for his botanical work was a small honorarium in 1949 from the Commonwealth and State Governments.

The earlier volumes of the "Flora" were out of print in less than twenty years, and the later volumes soon followed, so the need for a Second Edition was becoming acute by 1939. The book was a standard text in the University Botany Department, with its strong ecology school, and indispensable to many other botanical workers in Australia. Black was now eighty-four and it was not thought that he could embark on such a large undertaking; however, during the discussion on possible alternatives he agreed to take up the task again; he worked rather more slowly, but accurately and well, and we are fortunate indeed to have the work of his next twelve years, almost uninterrupted by illness and ended only by his death. In that time the new Part I (May 1943) and Part II (1948) were published, while Part III was nearly completed at the time of his death and appeared in print within nine months after (September 1952), with some biographical notes in the preface. Much material was already gathered up for Part IV, the preparation of which is being continued by others, with whom more responsibility for the remainder of the book will rest. The annual "Additions to the Flora of South Australia" have been mentioned; they continued during and after publication of the volumes of the "Flora," and formed quite a corpus of material ready to add to the Second Edition; they were his current notes and observations which he never relaxed from making, though the completion of his "Flora" would have been the occasion for many another man to do so.

Black was not a monographer, though he has to his credit a study of the flowering of *Pectinella* (a marine seaweed belonging to the flowering plants) 1913, and "A Revision of the Australian *Salicornieae*" (the difficult Samphires) 1919. A survey of the list of new species described by him shows that he covered the South Australian flora fairly impartially and thoroughly; he described several new species in the family Chenopodiaceae, and in the genera *Stipa, Calandrinia, Acacia, Swainsona, Frankenia, Eremophila, Goodenia* and *Brachycome*. It is of considerable interest to note that he scarcely ever named or altered the status of any species or form of *Eucalyptus;* an exception was *E. incrassata* Labill. var

protrusa J. M. B., an ephemeral name included in Ed. 1 only of the "Flora of South Australia"; no doubt he felt that this was ground where angels might fear to tread; the understanding of relationships within this genus is one of Australia's most challenging botanical problems. He had not the same inhibitions about the large and quite difficult genus *Acacia* in which he named 10 species and 4 varieties; nor the *Stipa* grasses.

The chief contributions of specialists towards his "Flora" were those of Dr. R. S. Rogers (Orchidaceae, in Edition I) and Mr. S. T. Blake (revision of Cyperaceae in Edition II), but Black was always very independent in his judgments and never accepted any work in his own field uncritically.

"The Flora of South Australia" is his chief monument, being the culmination of all his shorter botanical publications. In case one should forget the mastery of the tremendous range of detail which it implies, we might mention especially his series of studies in the difficult families Gramineae, Cyperaceae and Compositae, and his seven new genera in as many different families. The Australian flora, apart from the tropical rain-forests, is now so well known that to find new genera is rare; of those Black published four still stand; they are all monotypic containing rare species new to science, *viz., Sarcozona* from Eyre Peninsula, Broken Hill, etc., *Clelandia* from Wilpena Pound, *Uldinia* from Ooldea, and *Embadium* from west of Lake Torrens; they were published in the "Additions" series under the dates quoted in the "List of new genera . . . ." appended to this obituary. Of Black's three genera not at present standing, *Pectinella* (1913) had a peculiar and obscure submarine life history which had long kept its generic rank in doubt; Black set himself to discover the facts which he at first thought were sufficient to distinguish it from existing genera, but by 1922 he had abandoned his own genus for one of the old ones, *Cymodocea*. *Griffithia* (1913) turned out to be a rare species in South Australia already described as *Helipterum oppositifolium* S. Moore (1897) for Western Australia, he soon discovered this and apparently at once regretted having distinguished the plant generically from *Helipterum*. *Hymenocapsa* (1925) is a rare little plant which had already puzzled von Mueller and Tate, even as to its correct family status, and Black's new genus was an episode on the way to getting it suitably placed. Naturally his later judgments about the limits of genera had more of the necessary experience behind them and they were made whenever possible only after consultation with specialists.

Many Australian plants are of great anthropological interest for their use by the aboriginals; one might mention *Duboisia, Nicotiana* and *Solanum;* in the two last there were still problems of the delimitation of species for Black to cope with and some new ones to be recognised.

Black's other scientific activities included services to the Royal Society of South Australia (to which he was elected in 1907) as Council Member 1927-31, then as Vice-President 1931-33, and President in 1933-34; in 1945 he was elected an Honorary Fellow of the Society; he was also sometime Chairman of its Field Naturalists' Section. Black was really the unofficial referee for many a systematic botanical problem which presented itself to the State officers of the Department of Agriculture, and he always dealt most willingly with such questions; the Government was aware of these services, and he received the Royal recognition of M.B.E. in 1942.

His attendance at the meetings of the Australasian Association for the Advancement of Science appears to have been limited to those meetings held in Adelaide, of which there have been only four, apart from a few sessions of the British Association during its Australian visit of August 1914. The first Adelaide meeting was held in 1893 and Black was not a member, but he joined for the

1907, 1924 and 1946 meetings, though not for the British Association in 1914. In 1907 the botanist, J. H. Maiden, was President of Section D (Biology) and gave the valuable presidential address, "A Century of Botanical Endeavour in South Australia." This was right into Black's hands and impressed him greatly. In 1924 he gave a paper himself to Section M (Botany) on Nomenclature, which—unlike many a paper on this subject—was perfectly lucid. In 1946, though already ninety-one, he also attended, especially the Herbarium Sessions then held.

In 1930 he went abroad again and attended the Fifth International Botanical Congress at Cambridge, representing the University of Adelaide, the Royal Society of South Australia, and the Melbourne Botanic Gardens; this must have been a stimulating experience for him; he took part in the discussions on nomenclature and voiced his opinion against the principle of having chosen specific names conserved in the International Rules of Botanical Nomenclature—a never-ending bone of contention among botanists and others who use plant names; another Australian also present spoke for the opposite view. In this year of his presence at the Cambridge Congress, he was made an Associate *honoris causa* of the Linnean Society of London. These Associates are a select group which also includes another South Australian, the entomologist Mr. H. Womersley.

Besides the M.B.E. and A.L.S., Black received four other awards from the Australian scientific world. Besides being appointed Honorary Lecturer in Systematic Botany at the University of Adelaide from 1927, he received the Sir Joseph Verco Medal in 1930 from this Society; then the very appropriate Ferdinand von Mueller Medal (Australian and New Zealand Association for the Advancement of Science, 1932); the Australian Natural History Medallion (Field Naturalists' Club of Victoria, 1944), and finally the Clark Memorial Medal (Royal Society of New South Wales, 1946).

Black was modest and cheerful, with a rich personality and a refreshing sense of humour; he was a pleasant companion and formed some enduring friendships; enough has been said to indicate his passion for study in many fields throughout his life. His habit of continual recording was evidently very strong and he has left a series of personal diaries covering many years of his life. However, he seems to have destroyed nearly all his botanical correspondence once he had noted it, except for a few letters filed with appropriate herbarium specimens. Black was not a University man nor a trained botanist, but one of those gifted amateurs of high intellectual discipline who have so greatly enriched the science of systematic botany; Australia has reason to be profoundly grateful to another earlier amateur botanist in the same field—the great George Bentham, author of the "Flora Australiensis." Most of Black's botanical work was done at his Adelaide home in his study, with very modest equipment and library and largely with his own herbarium; he seems never to have settled in to a period of work at the large official herbaria; he had of course the freedom of the Herbarium of the University of Adelaide, where his teaching duties were nominal.

Three sons survive their father—Mr. G. M. Black of Gladstone, S.A., Dr. E. C. Black of Tranmere, S.A., and Mr. A. B. Black of Broken Hill, N.S.W.; his wife and his daughter, Mrs. Andrew, predeceased him; his son-in-law, H. W. Andrew, was a botanist in the South Australian Department of Agriculture. There are several grandchildren and great-grandchildren, with at least one professional botanist among them—Mr. Roger Black of Sydney University, a grandson.

A bibliography and a list of Black's new genera, species and varieties are appended; however, his name will always be remembered as the author of the excellent "Flora of South Australia."

LIST OF NEW GENERA, SPECIES AND VARIETIES PUBLISHED BY J. M. BLACK

Compiled by J. B. Cleland

TOTAL—7 genera and approximately 180 species and 40 varieties.

NEW GENERA

PECTINELLA, 1913 (= *Cymodocea*) in Potamogetonaceae.
SARCOZONA, 1934, in Aizoaceae.
HYMENOCAPSA, 1925, in Tiliaceae (= *Gilesia* in Sterculiaceae).
CLELANDIA, 1932, in Violaceae.
ULDINIA, 1922, in Umbelliferae.
EMBADIUM, 1931, in Boraginaceae.
GRIFFITHIA, 1913 (= *Helipterum*) in Compositae.

NEW SPECIES AND VARIETIES

POTAMOGETONACEAE—
Cymodocea Griffithii.

SCHEUCHZERIACEAE—
Triglochin ovoidea, T. hexagona.

GRAMINEAE—
Dichanthium humilius; Aristida biglandulosa; Stipa dura, S. horrifolia = *S. Drummondii* Steud., *S. plagiopogon, S. indeprensa, S. multispiculis, S. mundula, S. breviglumis* = *S. verticillata Nees.; Agrostis limitanea; Eriachne Isingiana; Danthonia geniculata, D. auriculata; Triodia aristata* = *T. irritans* R. Br., *T. lanata, T. longiceps; Eragrostis confertiflora, E. infecunda; Poa humifusa, P. halmaturina.*
Varieties—*Eragrostis interrupta* var. *densiflora* = *E. confertiflora; Stipa falcata* var. *minor, S. semibarbata* var. *gracilis, S. setacea* var. *latiglumis, S. eremophila* var. *dodrantaria* = *S. plumigera* Hughes, *S. pubescens* var. *maritima, S. pubescens* var. *comosa* = *S. Blackii* Hubbard, *S. scabra* var. *auriculata; Chloris divaricata* var. *minor; Eriachne ovata* var. *pedicellata* = *E. mucronata* R. Br..

CYPERACEAE—
Cyperus Clelandii = *C. dactylotes* Benth.; *Schoenus racemosus, S. monocarpus* (*Tetraria monocarpa, Cladium monocarpum*) = *S. Carsei* Cheesm., *S. tesquorum; Tetraria halmaturina* (*Heleocharis halmaturina*); *Cladium gracile* (= *C. laxum* (Nees) Benth.); *Gahnia hystrix; Bulbostylis Eustachii* (posthumous).
Varieties—*Cyperus eragrostis* var. *pauperata, C. exaltatus* var. *minor* (omitted in 2nd Ed.).

RESTIONACEAE—
Lepyrodia valliculae.

CENTROLEPIDACEAE—
Centrolepis Murrayi.

JUNCACEAE—
Varieties—*Juncus polyanthemos* var. *major.*

LILIACEAE—
Lomandra densiflora, L. fibrata.
Varieties—*Thysanotus Patersonii* R. Br. var. *exfimbriatus; Bulbine semibarbata* Haw. var. *depilata.*

IRIDACEAE—

Moraea xerospatha var. *monophylla.*

PROTEACEAE—

Grevillea quinquenervis, G. muricata = *G. Rogersi* Maiden, *G. umbellifera.* Varieties — *Hakea ulicina* R. Br. var. *latifolia, H. Ivoryi* Bailey var. *glabrescens.*

LORANTHACEAE—

Loranthus diamantinensis.

POLYGONACEAE—

Muehlenbeckia coccoloboides.

CHENOPODIACEAE—

Chenopodium melanocarpum (*Ch. carinatum* var. *melanocarpum*), *Ch. desertorum,* (*Ch. microphyllum* var. *desertorum*), *Ch. insulare; Atriplex cordifolia, A. crassipes; Bassia articulata, B. decurrens, B. ventricosa, B. limbata; Kochia scleroptera, K. enchylaenoides* (*K. tomentosa* var. *enchylaenoides*), *K. excavata* and var. *trichoptera, K. Cannonii, K. coronata; Threlkeldia diffusa; Pachycornia triandra* (F. v. M.) J. M. B., *P. tenuis* (Benth.), J. M. B.

Varieties—*Atriplex campanulata* Benth. var. *adnata, A. leptocarpa* F. v. M. var. *acuminata* = *A. acutibractea,* R. H. Anders. *A. Lindleyi* Moq. var. *quadripartita; Bassia paradoxa* (R. Br.) F. v. M. var. *latifolia, B. uniflora* (R. Br.) F. v. M. var. *incongruens* (Ed. I, Additions), *Babbagia acroptera* var. *acuminata* and var. *deminuta; K. tomentosa* (Moq.) F. v. M. var. *appressa* (Benth.) J. M. B. *K. triptera* Benth. var. *pentaptera; Arthrocnemum halocnemoides* Nees var. *pergranulatum,* and var. *pterygospermum.*

AMARANTHACEAE—

Trichinium seminudum, now *Ptilotus seminudus; Amaranthus grandiflorus* (*A. Mitchellii* var. *grandiflorus* J. M. B.).

Varieties—*Ptilotus Murrayi* var. *major; Trichinium helipteroides* var. *minor.*

AIZOACEAE—

Sarcozona Pulleinei (*Carpobrotus Pulleinei*).

Varieties—*Trianthema crystallina* (Forsk.) Vahl. var. *clavata.*

PORTULACACEAE—

Portulaca intraterranea; Calandrinia remota, C. dipetala, C. spaerophylla, C. stagnensis, C. disperma; Anacampseros australiana.

RANUNCULACEAE—

Ranunculus pentandrus = *R. parviflorus* L. var. *glabrescens* J. M. B..

CRUCIFERAE—

Blennodia pterosperma (*B. canescens* R. Br. var. *pterosperma* J. M. B.); *Menkea hispidula* = *M. villosula* (F. v. M. et Tate) J. M. B.; *Lepidium halmaturinum; Hymenolobus alatus; Hutchinsia cochlearina* = *Phlegmatospermum cochlearinum, H. eremaea* = *Ph. cochlearinum* (F. v. M.) O. E. Schulz var. *eremaeum* J. M. B.

LEGUMINOSAE—

Acacia rhetinocarpa, A. coronalis, A. rivalis, A. euthycarpa (*A. calamifolia* var. *euthycarpa* J. M. B.), *A. prolifera, A. Menzelii, A. barattensis, A. pinguifolia, A. tarculensis, A. quornensis; Daviesia nudula; Pultenaea cymbifolia* = *Gastrolobium elachistum* F. v. M., *P. quadricolor, P. trifida, P. trinervis; Indigofera longibractea* = *I. Basedowii* Pritzel; *Swainsona villosa, S. flavicarinata, S. reticulata, S. campestris, S. viridis, S. dictyocarpa, S. fissimontana, S. Morrisiana* = *S. Murrayana* Wawra., *S. microcalyx* and var. *adenophylla; Ptychosema stipulare* (1938) Central Aust. (not in Fl. S.A.).

Varieties—*Acacia retinodes* Schlecht. var. *uncifolia* and var. *oraria* (posthumous), *A. Bynoeana* Benth. var. *latifolia, A. sclerophylla* Lindl. var. *lissophylla, A. aneura* F. v. M. var. *latifolia; Cassia Sturtii* R. Br. var. *planipes* and var. *involucrata* (later a var. of *C. desolata*), *C. curvistyla* (1938) Central Aust. (not in Fl. S.A.); *Pultenaea graveolens* Tate var. *glabrescens, P. villifera* Sieb. var. *glabrescens; Swainsona canescens* (Benth.) F. v. M. var. *Horniana, S. oroboides* F. v. M. var. *hirsuta* J. M. B. = *S. Behriana* (F. v. M. herb.) J. M. B., *S. stipularis* F. v. M. var. *geniculata; Glycine sericea* var. *orthotricha.*

Zygophyllaceae—

Zygophyllum compressum, Z. tesquorum.

Rutaceae—

Boronia palustris Maiden et Black; *Correa calycina; Asterolasia muricata; Phebalium bullatum.*

Varieties—*Correa rubra* Sm. var. *orbicularis* and var. *megacalyx.*

Tremandraceae—

Tetratheca halmaturina.

Euphorbiaceae—

Euphorbia Murrayana = *E. Stevenii* F. M. Bailey, *E. Finlaysonii; Poranthera triandra; Beyeria subtecta.*

Varieties—*Phyllanthus thymoides* Sieb. var. *parviflorus.*

Rhamnaceae—

Pomaderris halmaturina.

Varieties—*Spyridium eriocephalum* Fenzl. var. *glabrisepalum, S. halmaturina* F. v. M. var. *integrifolium, S. subochreatum* (F. v. M.) Reiss. var. *laxiusculum.*

Malvaceae—

Plagianthus incanus; Hibiscus intraterraneus; H. crassicalyx (1933) Central Aust. (not in Fl. S.A.)

Dilleniaceae—

Hibbertia paeninsularis, H. crispula.

Varieties—*Hibbertia sericea* (R. Br.) Benth. var. *major* and var. *scabrifolia, H. stricta* R. Br. var. *oblonga.*

Frankeniaceae—

Frankenia orthotricha, F. foliosa, F. granulata, F. muscosa, F. crispa, F. cordata.

Varieties—*F. pauciflora* DC. var. *incrustata, F. serpyllifolia* Lindl. var. *eremophila* (= *F. eremophila* Summerh.).

Violaceae—

Clelandia convallis.

Thymelaeaceae—

Pimelea Williamsonii, P. continua.

Myrtaceae—

Melaleuca corrugata, M. monticola, M. oraria; Thryptomene Whiteae = *T. Elliottii* F. v. M.; *Calythrix involucrata.*

Varieties—*Baeckea crassifolia* Lindl. var. *pentamera; Eucalyptus incrassata* Labill. var. *protrusa* (not in Ed. II); *Melaleuca decussata* var. *ovoidea.*

Haloragaceae—

Haloragis semiangulata, H. ciliata.

Varieties—*Haloragis heterophylla* Brongn. var. *linearis.*

UMBELLIFERAE—

Uldinia mercurialis; Carum sioides = *Sium latifolium* L. var. *univittatum.*

Varieties—*Trachymene heterophylla* F. v. M. var. *Tepperi.*

EPACRIDACEAE—

Conostephium halmaturinum.

LOGANIACEAE—

Logania recurva, L. insularis.

GENTIANACEAE—

Limnanthemum stygium.

CONVOLVULACEAE—

Ipomoea lonchophylla, I. diamantinensis (posthumous).

BORAGINACEAE—

Halgania glabra; Plagiobothrys orthostatus; Embadium stagnense.

Varieties—*Heliotropium tenuifolium* R. Br. var. *parviflorum.*

VERBENACEAE—

Dicrastylis verticillata.

LABIATAE—

Varieties—*Prostanthera Baxteri* A. Cunn. var. *sericea.*

SOLANACEAE—

Solanum coactiliferum, S. centrale = *S. nemophilum* F. v. M.; *Nicotiana excelsior* (*N. suaveolens* Lehm. var. *excelsior*), *N. ingulba.*

SCROPHULARIACEAE—

Veronica parnkalliana.

Varieties—*Peplidium Muelleri* Benth. var. *longipes.*

BIGNONIACEAE—

Tecoma doratoxylon.

MYOPORACEAE—

Eremophila parvifolia, E. pentaptera, E. neglecta, E. MacGillivrayi.

Varieties—*E. MacDonnellii* F. v. M. var. *glabriuscula.*

GOODENIACEAE—

Goodenia unilobata, G. vernicosa, G. lunata, G. argentea, G. anfracta, G. modesta; Scaevola bursariifolia.

Varieties—*Scaevola linearis* R. Br. var. *confertifolia.*

CAMPANULACEAE—

Cephalostigma fluminale.

STYLIDIACEAE—

Stylidium inaequipetalum.

COMPOSITAE—

Brachycome tesquorum, B. lissocarpa, B. Tatei, B. neglecta, B. lyrifolia, B. campylocarpa; Minuria rigida; Calotis ancyrocarpa; Olearia microdisca; Senecio orarius; Pterigeron cylindriceps; Cassinia complanata; Griffithia helipteroides = *Helipterum oppositifolium* S. Moore; *Helipterum uniflorum; Helichrysum Mellorianum, H. Basedowii; Toxanthus Whitei* = *Millotia Kempei* F. v. M. var. *Helmsii* F. v. M. et Tate; *Angianthus Whitei* = *A. Burkittii* (Benth.) J. M. B.

Varieties—*Brachycome iberidifolia* Benth. var. *glanduligera* J. M. B.; *Calotis erinacea* Steetz var. *biaristata; Senecio Georgianus* DC. var. *latifolius, S. odoratus* Hornem, var. *obtusifolius; Helichrysum apiculatum* (Labill.) DC. var. *racemosum, H. ambiguum* Turcz. var. *paucisetum; Myriocephalus rhizocephalus* (DC.) Benth. var. *pluriflora; Angianthus brachypappus* F. v. M. var. *conocephalus; Sonchus asper* Hill var. *littoralis* J. M. B. = *S. megalocarpus* (Hook. f.) J. M. B.

SPECIES IN COURSE OF PUBLICATION AT BLACK'S DEATH

(Latin diagnosis still required)

Bulbostylis Eustachii J. M. B. (Cyperaceae).
Acacia retinodes Schlecht. var. *oraria* J. M. B. (Leguminosae).
Melaleuca corrugata J. M. B. (Myrtaceae).
Ipomoea diamantinensis J. M. B. et al. (Convolvulaceae).

SPECIES NAMED AFTER J. M. BLACK

Stipa Blackii C. E. Hubbard (1925).
? **Blackiella** Aellen (1938) = (Atriplex p.p.).
Bassia Blackiana Ising.
Salicornia Blackiana Ulbrich (1934) (*S. pachystachya* J. M. B. non Bunge).

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1943-1952 *Flora of South Australia.* 2nd Ed. Three parts only (incomplete). Pp. 683, figs. 964. Prepared and published by the same authorities as Ed. 1. (The Handbooks Committee is arranging for this edition to be completed).

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NATURALLY FUSED COAL ASH FROM LEIGH CREEK, SOUTH AUSTRALIA

BY GEORGE BAKER (COMMUNICATED BY S. B. DICKINSON)

Summary

Natural incineration of sub-bituminous coal at Leigh Creek generated ash which on fusion at higher temperatures was converted into three main types of clinker having differences in colour, texture, magnetic properties, density and mineralogical and chemical composition. Slow crystallization yielded holocrystalline masses of varying size, containing very little glass and over two dozen mineral species, noteworthy among which are magnetite, hematite, native iron, pyrrhotite, titan-augite, fassaite, gehlenite, perovskite and spinel.

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Communicated by S. B. Dickinson

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Natural incineration of sub-bituminous coal at Leigh Creek generated ash which on fusion at higher temperatures was converted into three main types of clinker having differences in colour, texture, magnetic properties, density and mineralogical and chemical composition. Slow crystallization yielded holocrystalline masses of varying size, containing very little glass and over two dozen mineral species, noteworthy among which are magnetite, hematite, native iron, pyrrhotite, titan-augite, fassaite, gehlenite, perovskite and spinel.

INTRODUCTION

Surface and sub-surface portions of the Upper Coal Seam, Lobe "D" in the North Basin, Leigh Creek Coalfield, six miles north of Copley, South Australia, have been naturally burnt. The Upper Seam averages 30 feet in thickness and consists of sub-bituminous coal, type C. Baked reddened shales and occasional patches of naturally fused coal ash resembling clinker have been developed along parts of the edge of the North Basin. These phenomena result from high temperatures generated by a pre-historic fire in the upper levels of the southern and western margins of the coal basin, above the water table.

The North Basin coal was found by Mr. S. B. Dickinson, Director of the South Australian Geological Survey, as a direct outcome of the discovery of the baked shales and fused ash, followed by subsequent recognition of Triassic fossil plants in less baked and unaltered portions of the shales.

Some two and a half dozen pieces of clinker, collected by Messrs. S. B. Dickinson, A. J. Gaskin, L. W. Parkin and the author, were examined in thin sections and polished surfaces. Four of these specimens have been separately chemically analysed.

The pieces of clinker are vesicular to scoriaceous, varying in size from 10 x 15 x 15 mm. to 120 x 95 x 60 mm. The larger specimens typically contain abundant black iron oxide minerals and are hence dark-grey to black. Smaller, lighter-coloured specimens, ranging from gray to greenish-gray and yellowish-gray, possess minor amounts of opaque minerals, usually as brownish-yellow hydrous iron oxides arranged around occasional gas cavities. The lighter-coloured (gray) fused ash is the more dominant type found in the field.

Most of the clinker is holocrystalline and fine-grained, but small quantities of glass occur in parts of all varieties of the fused ash. The mineralogy and chemistry of the clinker are complicated by the occurrence of a variety of constituents in different concentrations in the original coal and by some variations in the conditions to which these were subjected after the natural formation of coal ash. Clinkering of the ash, however, was largely a function of its chemical characters.

Baked and partially fused fossiliferous Triassic shales associated with the clinker have already been noted (Dickinson, 1946, p. 95), as presumably resulting from combustion in situ of a coal seam in portion of the North Basin at Leigh Creek.

The clinker outcrops at the surface and has been penetrated by bore ZV8. Unaltered shale, baked shale and clinker in that order were obtained in the bore between 17′6″ to 43′6″ below the surface. The shales immediately above the fused ash reveal marked brecciation, developed by gravitational collapse into the cavities left by the burnt-out coal seam beneath.

Many specimens of the clinker are slag-like masses bearing certain resemblances to vesicular lava, and in this respect are something like the "corite" (Bowen and Aurousseau, 1923, p. 447) of petroleum geologists. Several of the smaller vesicles in the scoriaceous and vesicular clinker are infilled with radial and concentric growths of white to pinkish-white minerals, thus causing the clinker to resemble amygdaloidal lava. A few of the smaller dark-coloured pieces of clinker with dense texture closely resemble dense basalt in hand specimens. The pieces of clinker are thus examples of "pseudo-igneous rocks."

Pseudo-igneous rock and baked shale from the combustion of coal seams have been noted in several parts of the world. Brady and Greig (1939) noted reddening and melting of shales in contact with a partly burned sub-bituminous coal seam near the head of Coal Canyon, Coconino County, Arizona. Lonsdale and Crawford (1928) noted pseudo-igneous rocks and baked shale from the burning of lignite from Freestone County, Texas. Professor Benson of Otago University, New Zealand, has under description a score of examples of fused, baked or reddened shales connected with coal seams in New Zealand. Other examples are known in various parts of America and Germany.

THERMALLY ALTERED AND FUSED ROCKS

Shales

The fine-grained argillaceous rocks associated with the clinker at Leigh Creek, South Australia, have been baked and reddened to various degrees according to their proximity to the burnt coal seam. The shales and the coal seam have low dips and the coal has been locally burnt from the surface down to the water table.

Of three examples of the shale examined from drillhole ZV8, one, the furthest from the clinker, is soft, grayish-brown and little affected by heat. The others, from near the clinker are yellowish-brown to reddish-brown and in parts have been thoroughly baked to a hard porcellanite.

Partially baked portions of the outcropping shale show traces of fossil plants. The woody structures and finely cellular leaf impressions of Thinnfeldia can still be recognized in them, also remnants of fossil fruit impressions. Originally-occurring dendrites along joint and bedding planes have been baked with the shale. Where in direct contact with the fused ash from the burnt sub-bituminous coal seam, thin layers of the shale have been locally fused along bedding planes. The fused layers have a superficial resemblance to light-brown and reddish-brown patches observed in some pieces of the clinker, so that some of the clinker might appear to be composed of fused shale. It is difficult to assess from the hand specimen, however, whether any of the ingredients of the shale actually became admixed with the coal ash to form the clinker, and the evidence from thin section inspection and chemical analysis indicates otherwise. Fragments of baked shale welded in parts of the clinker

show sharp outlines and only rare microscopically thin fused edges in contact with the clinker. The greater bulk of the clinker was evidently derived from the fusion of ash-forming mineral matter, etc. in the sub-bituminous coal.

Clinker

Physical Properties

The texture and colour of the clinker is variable, but three main types can be selected by reference to texture, colour and magnetic properties, thus :

(a) dense, dark bluish-gray, basalt-like clinker that is moderately magnetic and contains white minerals infilling several of the occasional gas cavities present.

(b) vesicular to scoriaceous, dark, almost black, heavy clinker, some pieces of which are dense in texture and strongly magnetic. Scoriaceous portions contain a few infilled gas cavities.

(c) vesicular, light-coloured clinker, pink and yellowish-green patches occurring in a normally light-gray to yellowish base. Specimens of type (c) clinker are feebly magnetic and more vesicular than the darker coloured clinker. The texture and colour of type (c) clinker are also more variable. This clinker contains occasional small pieces of baked shale firmly welded into a slaggy matrix, but these are quite distinct from the matrix and not admixed with it in any way. Many of the cavities in the vesicular portions are infilled with white minerals.

Colour variations in the clinker go hand in hand with marked changes in mineral composition and hence with chemical variations (cf. table IV), thus resulting in the general types of clinker set out above. This trend is illustrated by the following arrangement, where there is a threefold transition from the more commonly occurring, rather less strongly magnetic, gray clinker of type (b) :

Strongly magnetic TYPE (b) clinker
—dark grey to black
[Fe_2O_3 – FeO – rich
SiO_2–poor. Na_2O–rich]

Weakly to moderately magnetic TYPE (a) clinker
[Fe_2O_3 – moderate
SiO_2 – moderate
Na_2O – poor]

Less strongly magnetic TYPE (b) clinker
—grey to dark grey
[FeO – Fe_2O_3 – rich
SiO_2—poor. Na_2O—poor]

Weakly to non-magnetic TYPE (c) clinker
—light-grey to greenish-grey and yellowish-grey
[Fe_2O_3 – FeO – poor
SiO_2 – moderate. Na_2O – moderate]

The weight of individual clinker specimens varies from just under one ounce to seventeen ounces. Some darker pieces of type (b) clinker are much more strongly magnetic than others of type (b) that are not so darkly coloured. The remainder of type (b), which are moderately to weakly magnetic pieces, are generally rather more strongly magnetic than type (a) clinker and are the most abundant in the field. Most of the lighter-coloured pieces of type (c) clinker are weakly magnetic, some much more feebly so than others. A few small pieces of this type are non-magnetic.

The variability in density of various pieces of the different types of clinker is illustrated in table I. The densities were determined on a Walker's Steelyard in distilled water of temperature 15°C. The magnetic properties listed have been assessed from the strength of attraction of suspended pieces of clinker to an Alnico hand magnet.

TABLE I

Density	Magnetic Properties	Colour	General Type
3·14	strong	dark-grey to black	type (b)
3·12	strong	dark-grey to black	type (b)
2·97	weak to moderate	bluish-grey	type (a)
2·95	weak	greenish-yellow to reddish-brown	less vesicular var. of type (c)
2·92	moderate	dark-grey with yellowish patches	lighter-coloured var. of type (b)
2·92	moderate	dark-grey with greenish patches	vesicular var. of type (b)
2·82	weak	bluish-grey	vesicular var. of type (a)
2·80	weak to moderate	dark greenish-grey to yellowish-grey	vesicular var. of less magnetic portions of type (b)
2·72	weak to moderate	brownish-grey to yellowish-grey	darker var. of type (c)
2·70	very feeble	greenish-grey	type (c)
2·62	weak	greenish-yellow with light-grey patches	type (c)
2·62	weak	mottled light-grey pinkish- and yellowish-green	type (c)

The average density of the twelve pieces listed in table I is 2·86. The variability in density values from specimen to specimen is partly attributable to variation in vesicularity, but despite this factor, variability in density with colour, and hence with composition, can be detected (table II). Darker-coloured specimens have greater density values. This is due principally to the increased magnetite content in type (b) clinker and to the preponderance of a dark-coloured augite in the less strongly magnetic type (a) clinker. Lighter-coloured specimens with lower densities are practically void of magnetism. The degree to which vesicle infilling with white mineral matter has occurred, also affects the density values of different types of clinker.

In order to eliminate variations in density due to vesicularity, the densities of the four chemically-analyzed pieces of clinker (I to IV in tables II and IV) have been determined in the powdered form, with the following results (table II) :

TABLE II

No.	Density of Powder	Density of vesicular hand specimen (Range)	Type of Clinker	Silica Content
I	2·651	2·62–2·95	type (c)	32·2
II	2·963	2·82–2·97	type (a)	31·5
III	3·267	2·80–2·92	type (b) (moderately magnetic)	18·4
IV	3·276	3·12–3·14	type (b) (strongly magnetic)	19·4

These determinations reveal that there is a real variation due to chemical composition between the main types (a, b and c) of the Leigh Creek clinker, the density varying essentially with the silica content.

FUSIBILITY

The fusibility of the Leigh Creek sub-bituminous coal ash to form slag, has been determined as 1,250°C. to 1,290°C. (see Poole, 1946). Initial deformation in a reducing atmosphere occurred at 1,210°C. and blobbing at 1,295°C., while in an oxidizing atmosphere, initial deformation occurred at 1,300°C., and blobbing at 1,300° C., the residue after fusion in an oxidizing atmosphere being dark-brown and rough (Parker, 1948, p. 45).

Locally, the burning coal seam should have attained these temperatures in order to produce the natural clinker. Coal ash is a complex mixture of compounds and would not have a definite melting point. Partially fused and baked portions of the adjacent shale would not require such temperatures for their thermal alteration. Moreover, the temperatures in the adjacent shale were evidently not as high as those recorded by Brady and Greig (1939) for a trap-like rock formed by the melting of shale by a burning coal seam in Arizona. The lowest temperature of melting of the finely-ground rock was experimentally determined by Brady and Greig (1939, p. 118) as 1,117° C. At 1,232°C., the material had become all glass. Felspar persisted in small amounts to 1,212°C., so the temperature of the rock was definitely in excess of 1,117°C. and probably in excess of 1,212°C.

Many of the natural effects in the Arizona example are similar to those in the Leigh Creek occurrence. There was a reddening of the overlying shale (the Mancos Shale in Arizona) as in the Triassic shale at Leigh Creek. Locally, where natural chimneys formed, due to slumping, Brady and Greig noted that considerable melting of the shale had taken place. Melted rock flowed into cracks in the shale and also collected into small masses. Melted rock of this nature has not so far been noted in cracks in the Triassic shale at Leigh Creek, and the separate lumps of naturally formed clinker were derived from the fusion of a coal ash that had been produced during earlier phases of the incinerating process, not from the melting of shale.

Evidently the naturally fused coal ash at Leigh Creek cooled relatively slowly, since only small amounts of glass are found in parts of the fine-grained clinker. Although some clinker is found outcropping at the surface, much of it was formed under an overburden of Triassic sediments, and has been partly exposed by subsequent erosion of the overlying brecciated shale. Clinker occurs down to 43′6″ below the surface, where it is in place beneath baked

and brecciated Triassic shale, as shown from bore ZV8, hence supplies of oxygen must have been made available underground during burning; these supplies evidently came down natural funnels created by slumping. Hot blasts of gas generated in such funnels, assisted by the presence of natural fluxes in the coal ash, would readily lead to fusion of the coal ash and formation of the lumps of clinker.

The availability of constituents and the conditions requisite for their fusion, were obviously variable from place to place, in order to have generated magnetite plus sulphide-rich phases in parts, felspar-rich phases, titan-augite-rich phases, fassaite-rich phases, spinel-rich phases, perovskite-rich phases, apatite-rich phases and phases poor in some of these constituents in yet other parts. At the same time, certain of these phases, more particularly phases rich in iron oxides and sulphides, were affected by oxidation at high temperatures.

The cause of the natural generation of coal ash and its subsequent fusion to clinker in the North Basin at Leigh Creek, was evidently spontaneous combustion due to oxidation of the sub-bituminous coal seam. Burning started at the outcrop and proceeded downwards to the water table in a rank of coal suited to a relatively high rate of oxidation and one in which rate of oxidation would increase with depth from the weathered outcrop.

Chemical Composition of Leigh Creek Coal Ash and Clinker

The ash contents of the sub-bituminous coal from the North Basin at Leigh Creek have been determined (Poole, 1946) as :

Upper Seam, Lobe "D" = 7·49%
Lower Seam, Lobe "D" = 12·29%

The ash content of the sub-bituminous coal in the North Basin is only approximately one-half that of the Main Basin sub-bituminous coal at Leigh Creek. Only the upper seam in the North Basin caught fire, so that clinker was formed from the seam with the lowest quantity of ash (7·49%) available for fusion. The ash content of the upper seam, in an ultimate analysis by Dr. W. Ternent Cooke (see Parkin, 1947, p. 112), is given as 10·78%, while the accepted average ash content of this seam is recorded as 7·43% by Parkin (1947, p. 114), that of the lower seam averaging 13·56%.

The chemical composition of the coal ash from the North Basin, as set out by Poole (1946) and Parkin (1947, p. 111), is shown in table III :

Table III

SiO_2	21·18%	TiO_2	1·20%
Al_2O_3	14·85%	P_2O_5	1·96%
Fe_2O_3	12·28%	SO_3	14·81%
MgO	5·22%	Cl	3·56%
CaO	14·75%		
Na_2O	10·12%	Total	100·61%
K_2O	0·68%		

(Anal. T. W. Dalwood — see South Australian Dept. of Mines, Mining Review, No. 84, 1947)

Chemical analyses of four separate pieces of the clinker, carried out in the chemical laboratory of the Mineragraphic Investigations Section, Commonwealth Scientific and Industrial Research Organization, Geology Department, Melbourne University, show the following ingredients (table IV):

TABLE IV

Chemical Analyses of the Leigh Creek Clinker

	I	II	III	IV	V
SiO_2	32·23	31·51	18·43	19·44	25·5
Al_2O_3	20·68	20·42	25·48	19·71	21·6
Fe_2O_3	4·29	7·72	21·26	16·06	12·3
FeO	0·75	4·39	5·85	2·61	3·4
MgO	3·93	5·05	4·14	4·18	4·3
CaO	24·67	24·28	21·12	23·51	23·4
Na_2O	2·28	0·46	0·05	5·37	2·0
K_2O	0·87	0·15	0·01	0·22	0·3
H_2O (+)	1·51	0·81	0·80	1·87	1·2
H_2O (—)	0·53	0·62	0·15	0·35	0·4
CO_2	1·02	0·60	0·60	1·02	0·8
TiO_2	1·97	1·58	0·92	1·04	1·4
P_2O_5	1·56	1·88	1·36	3·21	2·0
MnO	0·32	tr.	0·02	0·07	0·1
CoO	tr.	tr.	tr	tr.	tr.
NiO	tr.	tr.	tr	tr.	tr.
Li_2O	nil	nil	nil	nil	nil
ZrO_2	nil	nil	nil	nil	nil
Cr_2O_3	tr.	tr.	tr.	tr.	tr.
BaO	0·01	nil	nil	0·01	—
Cl	0·09	0·09	0·03	0·60	0·2
S	2·13	0·50	0·01	1·62	1·1
CuO	nil	tr.	tr.	tr.	—
Total	98·84	100·06	100·23	100·89	100·0

(Analyses I to IV, anal. G. C. Carlos)

I — Type (c) clinker, Leigh Creek, South Australia.
II — Type (a) clinker, Leigh Creek, South Australia.
III — Type (b) clinker (less strongly magnetic portion), Leigh Creek, South Australia.
IV — Type (b) clinker (more strongly magnetic portion), Leigh Creek, South Australia.
V — Average of analyses I to IV.

For purposes of comparing the chemical composition of the clinker with that of the coal ash, the average composition of the clinker has been calculated (table IV, column V) and the ratios of the various oxides to silica have been determined for the average of the clinker analyses and for the coal ash. These ratios are set out in table V.

TABLE V

Ratios of oxides and silica

	Average Clinker	Coal Ash
$\frac{Al_2O_3}{SiO_2}$	0·85	0·70
$\frac{\text{Total Fe}}{SiO_2}$	0·61	0·58
$\frac{MgO}{SiO_2}$	0·17	0·24
$\frac{CaO}{SiO_2}$	0·91	0·70
$\frac{Na_2O}{SiO_2}$	0·08	0·48
$\frac{K_2O}{SiO_2}$	0·01	0·03
$\frac{TiO_2}{SiO_2}$	0·06	0·06
$\frac{P_2O_5}{SiO_2}$	0·08	0·09

The chemical variations between the various types of clinker and the significance of the variations and similarities between the oxide/silica ratios for the average clinker and the coal ash respectively, are discussed later in the paper under "Conclusions."

MINERAL COMPOSITION

The natural clinker from the Leigh Creek coalfield reveals considerable changes in the mineral composition (table VI) among the principal types (type (a), type (b) and type (c) clinker). These changes, linked with colour variations, density variations and changes in magnetic properties, find their best expression in chemical variations revealed by the analysis listed in table IV.

Parts of the clinker are rich in magnetite and allied minerals, with accompanying iron and copper sulphides. Other parts are richer in titanium minerals, while yet other parts are impoverished in these constituents, but richer in silicate minerals carrying lime, alumina, soda and magnesia. The content of sulphides of iron and copper, although never important in amount, does show a marked tendency for concentration more in the iron-rich phases than elsewhere.

The assemblage of iron minerals in parts of the clinker includes iron sulphides, various forms of iron oxides and native iron itself. This indicates that processes of both oxidation and reduction were able to operate quite locally in the vicinity of one and the same small specimen of clinker. The existence of

iron in three states of valence is apparently a reflection of the oxidation potential of the environment at the temperatures involved. Reducing environments favoured metallic iron, oxidising environments favoured ferric iron, while ferrous iron was the stable phase of the iron for a wide range in gaseous composition (cf. Barrett, 1945, p. 498).

Subsequent exposure of clinker at the surface, with further oxidation under atmospheric conditions and some hydration, led to the development of hydrous iron oxides from the ordinary processes of weathering of the iron minerals present.

Bowen and Aurousseau (1923, p. 445) noted that average shale shows a marked dominance of K_2O over Na_2O and an excess of alumina over that required to make alumino-silicates with the alkalies and lime. Fusion and recrystallization of such average shale would therefore lead to the formation of sillimanite and cordierite types of minerals. Absence of these groups of minerals from Leigh Creek clinker and the dominance of Na_2O over K_2O indicate that practically none of the components of the Triassic shale were absorbed into the constitution of the fused coal ash.

TABLE VI

Mineral Composition of the three main Types of Leigh Creek Natural Clinker

Mineral	Type (a) Clinker	Type (b) Clinker	Type (c) Clinker
Albite	o	o	o
Apatite	o	o	o
Biotite	o	–	–
Calcite (secondary in vesicles)	o	o	o
Chalcopyrite	o	r	–
Chalcopyrrhotite	r	–	–
Cryptocrystalline silica (secondary in vesicles)	r	r	r
Fassaite (var. of augite)	–	C	A
Gehlenite (var. of mellilite)	C	C	C
Glass (colourless to pale-yellow)	o	r	o
Goethite (needle-iron-ore)	r	r	–
Gypsum (secondary in cracks and vesicles and as crusts)	r	r	r
Hematite	C	C	r
Iron (native)	o	o	r
Lepidocrocite	r	–	–
Limonite	r	r	r
Maghemite (?)	r	r	–
Magnetite	C	A	r
Opal	–	–	r
Perovskite	o	–	o
Plagioclase (basic)	o	o	o
Pyrite	r	r	–
Pyrrhotite	o	o	r
Quartz (interstitial and in vesicles)	r	r	r
Spinel	C	o	C
Thomsonite	o	r	r
Titan-augite	A	–	–
"Zwischenprodukt"	r	–	–

A = abundant, C = common, o = occasional, r = rare

Opaque Minerals

The opaque minerals detected by examination of approximately 30 polished surfaces of the clinker, consist of native iron, pyrrhotite, chalcopyrite, rare pyrite and chalcopyrrhotite, considerable amounts of magnetite and hematite, some goethite, a little lepidocrocite and possibly maghemite.

The opaque minerals vary in quantity from place to place and from piece to piece in the clinker, being more abundant in strongly magnetic specimens and reduced to occasional specks in the light-coloured clinker of type (c).

Many of the textures and structures of the opaque minerals are submicroscopic and some can only be just detected under a 1/12N 1·30 oil immersion lens.

Native Iron

Native iron is not common in the clinker, but is nevertheless widely dispersed as small, well-rounded globules averaging 0·01 mm. across. It was evidently formed in the clinker at temperatures in excess of 1,030°C. The native iron is seldom located near gas cavities, being largely confined to parts of the clinker where reducing conditions were maintained. In subsequently weathered pieces of clinker, the native iron is not as noticeably altered as some of the pyrrhotite.

The native iron persists through all colour varieties of the clinker, although considerably reduced in amount and size in the lighter-coloured specimens. It sometimes shows thin rims of magnetite formed by heating in the presence of oxygen; these magnetite rims have often been martitized.

Globules of native iron are frequently associated with pyrrhotite. Droplets included in the pyrrhotite are rarely 0·006 mm. across, more usually 0·001 mm. and under. In many places, the droplets of native iron are coated partially or entirely with pyrrhotite. Very infrequently, discontinuous rims of uneven width around some of the native iron globules are composed of chalcopyrite.

Pyrrhotite

Pyrrhotite occurs mainly as small, disseminated angular to lobate areas and as rounded droplets. In its association with magnetite grains, it is sometimes moulded around the magnetite, but occasionally the pyrrhotite is enveloped by thick crusts of magnetite. These magnetite crusts follow the grain boundaries of the pyrrhotite and where such combinations form portions of the walls of gas cavities, the crusts of magnetite maintain a uniform thickness parallel with the walls of the cavities. This would indicate that the pyrrhotite has here been altered to magnetite by heating in an atmosphere containing oxygen, the relatively thick crust of magnetite protecting the core of the pyrrhotite from complete alteration by oxidation.

Pyrrhotite is by far the most common sulphide mineral in the clinker, but is never abundant. Rounded droplets are not uncommon and the small, often well-developed, irregularly lobate patches infill the interstices between some of the silicate minerals. The larger of the pyrrhotite areas measure 0·10 x 0·10 mm. and occasionally show (0001) cleavages; the smaller particles and many of the droplets are under 0·001 mm. across.

Weathered pieces of clinker show various stages in the alteration of the pyrrhotite. Products of oxidation and hydration are largely hematite and goethite, with a small amount of lepidocrocite (in type (a) clinker).

An uncommon feature in one piece of clinker (type (a)) is the occurrence in parts of the pyrrhotite of minute unmixing blebs of chalcopyrite. These are best pronounced in a "zwischenprodukt" (pl. I figs. 1 and 2) produced by par-

tial alteration of the pyrrhotite (cf. Ramdohr, 1950, p. 412) in one or two places. The "zwischenprodukt" is greyish-cream in colour and partly appears as mottled grains of angular shape. It evidently consists of sub-microscopically intergrown marcasite and magnetite developed from the break-down of the pyrrhotite. Solid solution of a few percent of $CuFeS_2$ in the FeS lattice is well known from experiment and is realized in nature at high temperatures of formation, as in the small sulphide globules enclosed in the initial products of crystallization of some magmatic rocks. The appearance of unmixing phenomena from such solid solution in the Leigh Creek clinker (pl. I, fig. 2), therefore points to a high temperature of formation.

The distribution of the pyrrhotite in the natural clinker tends to be somewhat streaky, indicating that parts of the original sub-bituminous coal were relatively high in pyritous mineral content, while other parts were impoverished in this ingredient.

Chalcopyrite

Most of the chalcopyrite was formed as occasional small grains, with few larger scattered grains. A narrow veinlet of chalcopyrite cutting through pyrrhotite in a polished surface of the type (a) clinker, is an unmixing feature and apparently allied to the ex-solution blebs of chalcopyrite elsewhere in the pyrrhotite.

Whereas some of the ex-solution bodies in the pyrrhotite are typically chalcopyrite, some are more like chalcopyrrhotite. As noted by Edwards (1947, p. 88), copper sometimes becomes precipitated as chalcopyrrhotite from solid solutions of chalcopyrite and pyrrhotite, under certain conditions of cooling. Such conditions have been partially fulfilled in portions of the Leigh Creek clinker, but their precise nature has not been assessed.

Pyrite

Pyrite is only a minor constituent of the natural clinker, occurring as rare small specks. The original pyrites (actually marcasitic in the Leigh Creek sub-bituminous coal), was largely converted to pyrrhotite on burning of the pyritous coal seam. At atmospheric pressures this change occurs at temperatures in the region of 690°C.

Small veinlets of secondary pyrite cut through an oxidized grain of pyrrhotite in one of the polished surfaces.

Magnetite

Parts of the clinker are strongly magnetic and show a multitude of small crystals of magnetite of varying size, more especially in the darker-coloured specimens of type (b) clinker. Lumps of clinker rich in magnetite and weighing up to half a pound, can be lifted by means of a small, but strong, Alnico hand magnet.

The magnetite is sometimes scattered through the fused rock as cubes and grains of less regular shape; sometimes the crystals are amassed into clusters.

Accompanied by their alteration products, the magnetite crystals often form the principal component lining the walls of numerous gas cavities. In parts, the magnetic grains are arranged in web-like growths, due to concentration along the crystal boundaries of the smaller, even-grained crystal aggregates of the silicate minerals. Magnetite has also formed as small included particles in pyrrhotite, the particles being of the same average size as included

droplets of native iron (q.v.). Magnetite crusts around pyrrhotite and magnetite cores enveloped by rims of pyrrhotite, have already been described (see section on pyrrhotite).

In most of the less magnetic pieces of clinker, much of the magnetite has been altered to pseudomorphs of secondary iron oxides. In parts of the feebly to non-magnetic pieces of clinker there has been complete oxidation and hydration of the original small quantity of magnetite, but in some parts both iron sulphides and iron oxides are virtually absent, their place having been taken by iron-bearing spinel.

A characteristic feature of the mode of occurrence of the magnetite in the clinker is the presence in the same field of view under the microscope of (i) patches with clean grains of structureless magnetite (associated with patches richer in the sulphide minerals) and (ii) adjacent patches of magnetite crystals containing ex-solution lamellae (in parts of the clinker impoverished in sulphide minerals). The un-mixing structures in the magnetite are composed of regularly arranged, uniformly narrow lamellae of much less strongly reflecting spinel, lying along the three octahedral directions in cubes of magnetite (cf. Ramdohr, 1950, p. 656) and along (100) planes in octahedral crystals. The spinel lamellae have a dark-grey colour under the reflecting microscope, but are somewhat lighter than the silicate minerals.

In some pieces of the clinker the magnetite forms a second type of mixed crystal with spinel. Narrow jackets of the magnetite enclose central cores of much lower reflecting spinel, while short lamellae along (111) directions in the magnetite rims are composed of more strongly reflecting hematite. Some of these hematite lamellae are isotropic and regarded as maghemite. A few of the magnetite crystals possess later-formed rims of spinel.

The occurrence of magnetite crystals with ex-solution lamellae of spinel in some parts of the clinker, indicates relatively slow cooling, very much slower than in artificial slag. For this reason, FeO minerals such as wüstite (Mason, 1943, p. 101) would not be expected, even though reducing conditions that would favour the development of wüstite existed in parts of the clinker. Moreover, any FeO available is likely to combine with the available MgO and Al_2O_3 to form ferroan spinel rather than magnesiowüstite. Furthermore, wüstite is unstable below 575°C. (Mason, 1943, p. 174), tending to disintegrate into iron and magnetite.

Hematite

Hematite is a common constituent of the clinker, more particularly in less strongly magnetic, darker-coloured pieces. In lighter-coloured pieces of the clinker, all original magnetite and most of the sulphides have been converted to hematite and the only remaining fresh original iron minerals are rare small particles and droplets of the sulphides and sometimes native iron, preserved from alteration within the silicate minerals.

Pseudomorphs of hematite after cubes and grains of magnetite are a frequent feature of some of the moderately magnetic lumps of clinker. Hematite commonly occurs after the magnetite lining the walls of gas cavities, whereas magnetite crystals surrounded by silicates and situated away from gas cavities in the same piece of clinker, frequently remain unaltered.

The hematite often forms rims to magnetite crystals, alteration proceeding from the edges inwards and occasionally penetrating along octahedral planes in typical martitization structures. The formation of these structures may have been assisted by the high temperatures developed during burning of the sub-bituminous coal seam, thus resulting in "hitzmartite" from oxidation under heat of both the pyrrhotite and the magnetite.

Partial and complete pseudomorphs of hematite after pyrrhotite are not uncommon. One example, a double pseudomorph, provides evidence of pyrrhotite first altering to magnetite and then to hematite, spindle- and needle-shaped areas of hematite penetrating remnants of the magnetite that partially replaces pyrrhotite.

Some hematite-like pseudomorphs in magnetic portions of the clinker have brownish internal reflections, are isotropic and show grayish-white colours in polished surfaces, indicating the presence of a certain amount of maghemite. Mason (1943, p. 117) notes that artificial Fe_3O_4 readily oxidizes to $\gamma - Fe_2O_3$, so it is likely that the magnetite developed in the clinker could just as readily be oxidized to form ferromagnetic iron oxide (maghemite) under conditions of slow oxidation at the lower temperatures ruling during cooling phases.

Goethite and Lepidocrocite

The group of the secondary iron hydroxides is represented largely by the needle-iron-ore mineral goethite and very little of the ruby mica lepidocrocite These minerals have resulted from weathering of portion of the iron sulphides and iron oxides in the clinker and from partial alteration of the droplets of native iron. Their development was no doubt aided initially by partial decomposition of such of the pyrrhotite grains as were heated in air along the walls of gas cavities in the clinker.

The limonite group of minerals is more common in the moderately to weakly magnetic pieces of clinker and often more prominent lining the walls of gas cavities in more vesicular pieces of clinker.

In limonitized portions of the "zwischenprodukt" showing unmixing of chalcopyrite in the type (a) clinker, areas formerly occupied by blebs of chalcopyrite are now represented by holes, while in the less altered "zwischenprodukt" itself, blebs of chalcopyrite are still preserved (pl. I fig. 2). This shows that chalcopyrite is destroyed much more slowly in the "zwischenprodukt" than in nearby limonitized areas.

Translucent and Transparent Minerals

Translucent and transparent minerals forming the matrix (pl. I figs. 3 & 4) in which are set the opaque minerals already described, consist of the gehlenite variety of mellilite, titan-augite, fassaite, albite, some basic felspar, spinel, perovskite, biotite, quartz and apatite. All of these minerals, however, are never found in one and the same piece of clinker, (cf. Table VI). A little glass occurs in parts of the clinker, more especially in type (a) and in a few pieces of type (c) clinker, but no important amounts of glass are present anywhere in the clinker.

White minerals infilling certain gas cavities in all the types of clinker consist of calcite, crystalline and cryptocrystalline silica and zeolitic minerals such as thomsonite (pl. I fig. 5). The thomsonite is biaxial positive and has a refractive index approximately the same as that of Canada balsam. A little opal is also present in some pieces of type (c) clinker. Some cavities and cracks exposed in clinker outcropping at the surface of the ground, have been partially infilled with secondary gypsum that is forming today in the Leigh Creek region and which has its origin in cyclic salts.

Textures vary in the different types of clinker, principally as a result of the disposition of the translucent and transparent minerals. The textures are mainly amygdaloidal, fine-grained basaltic (pl. I figs. 3 & 4) and vesicular to scoriaceous. In the hand specimens some pieces of the clinker resemble dark, dense volcanic rock such as basalt, with gas cavities in parts containing radial mineral aggregates, while under the microscope the resemblance is equally as striking, (pl. I fig. 5).

Type (a) Clinker

Type (a) clinker has a marked basaltic texture. It is not strongly magnetic and its dark colour is largely due to purple pyroxene plus a certain amount of magnetite (and hematite) as dust and small crystals. The purple pyroxene is biaxial positive, with 2V near 30°, refractive index = 1·695, birefringence = 0·020, extinction angles are up to 43°, dispersion is strong ($r>v$) and pleochroism is weak from purple to grayish-yellow. In view of the titanium content (1·58%) revealed in the analysis of type (a) clinker (table IV, column II), added to the fact that other titaniferous minerals are very rare, this pyroxene is evidently a richly titaniferous augite (titan-augite can contain up to 4·84% TiO_2). It is an abundant mineral in the type (a) clinker (cf. table VI).

The basic plagioclase in type (a) clinker and all other types of the clinker (pl. I fig. 4), is biaxial negative, with a low 2V and extinction angles up to 30°. More common in some parts of the clinker are crystals of albite which account for the higher soda content of certain pieces of clinker, as for example the more strongly magnetic portions of type (b) clinker (see table IV, column IV).

Next in abundance to titan-augite in the type (a) clinker, is a colourless to very pale yellowish mineral with low birefringence and straight extinction. It is uniaxial negative and has a refractive index within the range 1·660 to 1·665, indicating a species of the mellilite group having the proportions äkermanite = 20, velardenite = 80. These properties are closest to those of the gehlenite variety of mellilite.

Very little quartz is present in the type (a) or in any other type of the Leigh Creek clinker. It infills rare interstitial areas and occurs in some of the infilled gas cavities associated with granular aggregates of calcite. It has also been observed as rare inclusions in the albite.

Biotite, pleochroic from pale lemon-yellow to pale reddish-yellow, forms incipiently developed small patches and occasional well-developed plates showing basal cleavage. It is confined solely to the type (a) clinker.

Colourless to pale-yellow glass is interstitial in isolated patches of the clinker. It is largely isotropic, but portions are weakly birefringent with biaxial positive optical figures. The isotropic glass has a refractive index of 1·560. It contains numerous needles of apatite, thus accounting for the bulk of the 1·88% P_2O_5 revealed by chemical analysis (table IV, column II). Needles of apatite also occur in the biotite to a lesser extent.

Multitudes of minute, greenish-coloured, isotropic crystals with cubic form are iron-magnesia spinel. They are scattered throughout the type (a) clinker and account for the higher MgO content (table IV). The majority of these crystals do not show the magnetite rims noted around spinel in polished surfaces of the other types of clinker, but the inner cores of some magnetite grains are mixed crystals of spinel and magnetite. Sometimes the spinel itself shows slight zoning in thin sections.

Several small, octahedral, skeletal and irregular crystals about the same size as the spinel crystals, show brown internal reflections in polished surfaces. In thin section, some of these crystals are reddish-brown and since they show birefringence, are not to be confused with spinel or with maghemite. In polished surfaces they have a bluish-grey colour and a lower reflectivity than spinel. They are evidently crystals of perovskite, some of which occasionally form nuclei within the magnetite crystals.

Type (b) Clinker

Type (b) is a dark-coloured clinker, parts of which are more strongly magnetic than others. Clusters and disseminated grains of magnetite are set in a "basaltic" matrix of fassaite and gehlenite, with variable amounts of basic plagioclase and albite.

Spinels in the type (b) clinker usually have rims of magnetite. Sometimes the core of spinel is small compared to the crust of magnetite, but all gradations are present from this to crystals having large cores of spinel and much-reduced rims of magnetite.

Larger gas cavities in type (b) clinker are lined with hematite followed by a layer of clear calcite, then a very narrow band of limonite-stained carbonate. The remainder of such cavities is infilled with dusty aggregates of calcium carbonate crystals that include angular quartz grains and occasional clots of limonite. Smaller cavities are characteristically round to sub-round in outline and are typical small gas cavities; larger cavities of irregular outline are sometimes lobate and result from the coalescence of several smaller gas bubbles.

Type (c) Clinker

In the lighter-coloured pieces constituting type (c) clinker, the yellowish to greenish colour is caused by the development of pale yellowish-green fassaite to the complete exclusion of the purple augite so characteristic of type (a) clinker. The fassaite is weakly pleochroic from lemon-yellow to pale greenish-yellow. It shows 90° cleavages and occasional 8-sided cross sections. The refractive index varies from 1·690 to 1·700 and extinction angles range from 0° to 26° on (110) cleavages. Some crystals of the fassaite show continuous zoning, others more rarely show discontinuous zoning. In some of the zoned crystals an outer zone, rather more yellowish in colour, extinguishes at up to 16° less than the greenish-yellow core. The more yellow rim is evidently richer in alkalies.

The next most common constituent to the fassaite is gehlenite. Basic plagioclase, albite and a little glass are present, also pale-yellowish to colourless spinel crystals, long colourless needes of apatite (mainly in the glass) and dark reddish-brown perovskite.

Some of the spinels show zoning in polished surfaces of type (c) clinker. In reflected light they have dark-grey centres and rather lighter-grey rims richer in iron. The spinel crystals are similar in size and abundance to the magnetite grains in more strongly magnetic portions (i.e. type (b)) of the clinker. They are therefore to type (c) what the magnetite is to type (b) clinker. Type (c) grades into type (b) clinker by diminution of spinel and influx of magnetite and allied minerals, a phase in the transition being one in which the magnetite possesses ex-solution lamellae of spinel.

Polished surfaces of type (c) clinker reveal negligible amounts of iron sulphides and iron oxides, so that type (c) clinker, typified by a fassaite-gehlenite-spinel assemblage, was impoverished in iron, indicating a marked variation from type (a) and type (b) samples of the Leigh Creek clinker. Such a variation is best explained in terms of the availability of different amounts of different ingredients from the sub-bituminous coal ash, types (a) and (b) developing from more iron-rich areas, type (c) from portions originally richer in the kaolin group minerals that supplied alumina and silica dominantly.

Numerous gas cavities in the type (c) clinker are occasionally lined with thin crusts of limonite. The larger cavities usually remain open, the smaller cavities are frequently infilled with calcite, rarely with cryptocrystalline and opaline silica and in places with secondary gypsum.

CONCLUSIONS

The Leigh Creek natural clinker was formed as relatively small lumps from the fusion of sub-bituminous coal ash at temperatures in the region of 1,300°C.

Natural combustion of parts of the Lobe "D" North Basin coal at Leigh Creek evidently arose from the characteristic liability of sub-bituminous coal to spontaneous ignition under certain conditions. The avidity of this type of coal to take up oxygen from the atmosphere is well known. The exothermic nature of such a process led to increased temperatures in the coal and ultimately the onset of combustion.

The outcrop coal had evidently reached a stage suitable for such reactions to develop. Its location in a sub-arid region suggests drying-out and powdering, thus yielding increased surface areas for oxygen absorption. The presence of marcasite in the coal possibly assisted the process by itself oxidizing and evolving heat, thus providing additional areas of increased temperature. These would be areas of increased oxygen absorption, thus accelerating the exothermic process. Combustion resulted in loss of volatiles and the generation of ash.

The ash, consisting of inorganic salts and extraneous mineral matter, contained such ingredients as quartz, clay minerals, sericite, iron and copper sulphides, calcium, magnesium and iron carbonates and sulphates, titanium and phosphorus in some form or other and rare detrital accessory minerals. Soda, potash and trace elements were also present.

During combustion, ferric oxide and sulphur dioxide would be generated from the sulphides; lime, magnesia and ferrous oxide from the carbonates. Sulphur dioxide and carbon dioxide were largely lost by volatilization at the same time as most of the chlorine was driven off.

Subsequent fusibility of the coal ash ingredients depended mainly on the chemical character of the inorganic ash and the adventitious mineral matter left after incineration had removed the volatile materials (hydrogen, carbon dioxide, sulphur dioxide and chlorine). Where sufficiently high temperatures were attained, clinkering of the ash occurred, because there existed mixtures of ingredients containing the right amounts of natural fluxes to promote and facilitate fusion of the silica-alumina content, with the attendant formation of alumino-silicates containing proportions of certain elements derived from the fluxes. Thus, in the presence of abundant lime, the ferric oxide, the magnesia and the alkalies (more particularly soda in some parts), combined to result in strong fluxing effects while the presence of sulphur in the iron sulphide also contributed to the promotion of clinkering. The net result was the formation of three principal types of clinker, with variable amounts of iron oxides, magnesium aluminate and alumino-silicates. In all pieces of the clinker examined, however, there remained complete freedom from residual ash or unfused mineral matter. Cooling processes were sufficiently slow to allow the bulk of the fused ash to recrystallize, leaving very little glass.

For the formation of magnetite in the clinker, the ferric oxide produced during coal ash development must be assumed to have undergone reduction. Carbon, hydrogen and sulphur can act as reducing agents to bring about the conversion of ferric oxide to magnetite, rising temperatures increasing the rate of reaction and pressure being without significance (Mason, 1943, p. 127). In the Leigh Creek clinker, magnetite evidently formed from ferric oxide in the presence of some carbon, hydrogen, sulphur and fluxes at the temperatures (about 1,300°C) necessary to fuse the ingredients available from coal ash. A little magnetite also formed where native iron and pyrrhotite were heated in the presence of oxygen.

At some stage of clinker formation, the evidence provided in polished surfaces shows that some of the ferrosic oxide (magnetite) was converted back to ferric oxide (hematite). Such a change presumably occurred during cooling phases. Mason (1943, p. 128) states that when magnetite is heated in air to 200° C., it is slowly oxidized to hematite. This reverse process in the relationships of Fe_2O_3 to Fe_3O_4 is common and widespread, oxidation commencing at the rims and along octahedral planes in the magnetite. This oxidizing effect on the magnetite probably took place under alkaline conditions, for as Mason states (1943, p. 128), the pH of the medium in which the reaction takes place exerts an important influence in the oxidation of divalent to trivalent iron, alkaline solutions probably having an oxidizing effect on magnetite, while neutral and acid solutions do not. Although much of the hematite evidently developed in this way during the end phases of cooling of the natural clinker at Leigh Creek, some was undoubtedly formed under atmospheric conditions, especially where portions of the clinker occurred in the zone of weathering. Some of this hematite became hydrated to limonitic minerals.

The alteration of native iron and pyrrhotite (formed at the higher temperatures) to hematite, no doubt followed a similar sequence of events to that of the oxidizing effects on magnetite during cooling phases and during subsequent periods of weathering.

Unmixing structures between magnetite and spinel were developed in the earlier phases of clinker formation and at the higher temperatures, when magnesium aluminate was crystallizing. This is evident in some of the magnetite-spinel mixed crystals that have cores of spinel and rims of magnetite, because many of the magnetite rims have been partially martitized, evidently during cooling phases when hematite was being generated from magnetite generally.

The more important chemico-mineralogical variations between the three main types (a, b, and c) of clinker, lie in the iron sulphide—iron oxide—magnesium oxide—titanium oxide relationships, and in the marked diminution of silica with increase in total iron in the transition from non-magnetic to magnetic pieces of the clinker.

The average silica content of the clinker (table IV, column V) is little more than that of Leigh Creek coal ash (table III), but there is a marked fall in silica content from the lighter-coloured clinker of types (c) and (a) to the darker-coloured clinker of type (b). Since the silica is essentially incorporated in the silicate minerals titan-augite, fassaite, gehlenite and felspars, any variations in the silica content must be reflected in an increase of these minerals in portions of the clinker higher in silica. The cause for such variation is entirely fortuitous, depending essentially upon a sporadic distribution of silica in the original sub-bituminous coal, with greater concentration of the silica into some portions of the coal ash than in others. Possibly small runs of fine quartz sand in the coal gave rise to the pieces of clinker with the higher silica contents.

With decrease of silica content in the clinker there is a pronounced rise in total iron content, type (a) containing two and a half times as much as type (c), and type (b) four to five times as much as type (c) clinker. The greater content of iron oxides and iron sulphides in type (b) clinker is a reflection of these variations, with type (a) a transition type as far as total iron is concerned. Variation in the ratio of Fe_2O_3 to FeO in type (b) clinker (table IV, columns III and IV) can be traced to variable alteration of magnetite to hematite. The ratio of the total iron content to silica content of the average clinker shows a small increase compared with the ratio for the coal ash, but the variation can be accounted for by errors of sampling. The iron sulphide content, represented largely by pyrrhotite, is of sporadic distribution

in the various types of the clinker, attributable to an original patchy occurrence of pyritous matter in the sub-bituminous coal.

The alumina content remains much the same in the several types (a, b, and c) of clinker, but is a little higher than in the North Basin coal ash (cf. oxide ratios in table V). To account for this increase it might therefore appear that some alumina was added from the associated shale. The low potash contents of the clinker (see table IV), however, tend to negate this idea, especially as the ratio of potash to silica in the average clinker analysis (table V) is actually less than the ratio in the coal ash.

The ratio of magnesia to silica (table V) in the average clinker is markedly lower than that for the coal ash. If originally present partly as $MgCl_2$ or $MgCO_3$ in the coal ash, some of the magnesia could have been lost on fusion, since $MgCl_2$ has a melting point of 708° C. and $MgCO_3$ decomposes at 350°C., while the clinker was formed at far higher temperatures. Shortly prior to complete fusion and recrystallization of the coal ash, the magnesium was probably in the form of $MgSO_4$ which has a melting point of 1,124°C. Variation of magnesia within the clinker itself is expressed by variation of its spinel content. The highest magnesia content is found in type (a) clinker, where spinel is most common as small crystals. The magnesia in type (c) clinker has to be assigned partly to spinel and to some extent to fassaite, while in type (b) clinker the magnesia is partly accounted for by the spinel lamellae in host magnetite and partly by fassaite. Variations in the final amounts of magnesia locked up in the clinker can be due either to variable concentrations of magnesium compounds in the coal ash, or to variable degrees of vaporization of less stable magnesium compounds on fusion, or both.

In connection with the relationship between magnetite and spinel in artificial slags, Edwards (1949, pp. 44-45) notes narrow margins of magnetite around spinel. The spinel commenced to crystallize prior to magnetite in the artificial slag, though some of the magnetite may have crystallized concomitantly with it. The interesting fact is that most of the spinel and magnetite formed independently of each other, although crystallizing at much the same time. Since both compounds have similar atomic structures, with constituent ions of comparable radii and valency, solid solution would be expected. Since none is present, Edwards concludes that the extent of possible solid solution is presumably limited by the difference in size of the Fe^{3+} and the Al^{3+} ions ($Fe^{3+} = 0{\cdot}67$ Å, $Al^{3+} = 0{\cdot}57$ Å). In the natural clinker from Leigh Creek there occurs three principal relationships between the spinel and the magnetite, these being:

(i) magnetite moulded around spinel,
(ii) ex-solution intergrowths of spinel (as lamellae) in magnetite (host), and
(iii) core of magnetite in the spinel (these are of rare occurrence).

Evidently spinel and magnetite were crystallizing at slightly different times in different portions of the clinker and under rather different conditions, but wherever the relationships between spinel and magnetite can be established, spinel mostly crystallized first. As in artificial slag described by Edwards (1949), many crystals of spinel and magnetite developed independently of one another in the Leigh Creek natural clinker. In parts of the clinker (type (a)), magnetite continued to crystallize after the formation of a limited number of spinel-magnetite mixed crystals, thus producing compound crystals having rims of magnetite around ex-solution intergrowths of spinel and magnetite. In parts of this type of clinker, however, spinel often occurs alone with neither rims nor intergrowths of magnetite, although it does show chemical zoning from the alternation of iron-rich and iron-poor zones.

Most spinels crystallized before magnetite in type (b) clinker, the later-formed magnetite characteristically forming rims around spinel. In rare places, however, spinel encloses earlier-formed magnetite.

Spinel occurs almost to the exclusion of magnetite in type (c) clinker, because of the paucity of iron in parts of the coal ash that formed type (c) clinker. The formation of magnetite (host)—spinel (lamellae) intergrowths in only a transitional variety between the type (b) and type (c) clinker, is in accord with Edwards' (1949, p. 45) conclusion that the extent of possible solid solution between spinel and magnetite is limited, presumably by the difference in size of the Fe^{3+} and Al^{3+} ions.

Increase in the lime content of the clinker compared to the coal ash, as indicated by the CaO/SiO_2 ratios (table V), is partly accredited to the incoming of secondary lime minerals by the agency of present-day cyclic salts which find their way into the cavities of the vesicular to scoriaceous clinker. Variation in lime as between the clinker and coal ash, however, may also be attributable to differences in concentration of lime-bearing constituents in the sub-bituminous coal, differences that sampling for coal analysis may not have smoothed out.

The lime content is high in the clinker, being over twice as much as is normally found, for example, in basaltic rocks. This high lime content finds mineralogical expression in the abundance of gehlenite and fassaite in types (b) and (c) clinker and in the abundance of gehlenite and titan-augite in type (a) clinker. Portion of the lime content, however, has to be assigned to basic plagioclase, perovskite, apatite and possibly the small amounts of glass in the clinker itself, and to gypsum, calcite and thomsonite that infill some vesicles in the clinker.

Variations in soda content of the clinker are expressed mineralogically in terms of an increased development of albite in parts of the type (b) clinker and variable amounts of thomsonite in vesicular portions of the clinker as a whole. Marked diminution in the average soda content of the clinker, compared to coal ash, evidently results from loss by vaporization on fusion at the higher temperatures necessary for clinker formation. The slight decrease in potash content may be due to the same cause.

Although the titania content shows little variation from type to type in the clinker (table IV), it finds different mineralogical expression in the different types. It is located in the titan-augite in type (a) clinker, in the perovskite in type (c) clinker and partly in the perovskite, partly in the abundant magnetite in type (b) clinker. Comparisons of the TiO_2/SiO_2 ratios for clinker and coal ash show there has been little change in titania content during transition from coal ash to clinker. The reasons for the generation of different titanium-bearing minerals in the different types of clinker are obscure.

The P_2O_5 content is relatively high throughout the various types of clinker and is of the same order in clinker as in coal ash. The marked increase in amount in parts of type (b) clinker can be traced to the local development of abundant apatite needles.

Sulphur in the clinker is largely accredited to pyrrhotite. The pronounced variation in the sulphur content of different types of clinker (table IV), is plainly evident from polished surfaces, which reveal marked variations in the amounts of pyrrhotite from piece to piece and often from place to place in the same piece of clinker. Lesser quantities of both sulphur and chlorine in the clinker, compared to the coal ash, result from loss of these volatiles at the increased temperatures attained during fusion of coal ash to clinker. In type (c) clinker, sulphides are at a minimum development for the clinker generally; the high sulphur content revealed by chemical analysis (table IV, column I), is evidently due to abundant gypsum in vesicles.

ACKNOWLEDGMENTS

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EXPLANATION OF PLATE I

Fig. 1 Pyrrhotite altering to "zwischenprodukt" and needle-iron-ore. (x 75). Type (a) clinker, Leigh Creek, South Australia.

Fig. 2 Enlarged portion of pyrrhotite altering to "zwischenprodukt" (area illustrated in photo. 1), showing ex-solution bodies of chalcopyrite. (x 260). Type (a) clinker, Leigh Creek, South Australia.

Fig. 3 Basaltic texture of type (a) clinker (ordinary light), showing gehlenite (fresh and weathered), fassaite and calcite-infilled gas vesicle. Dark areas are spinel. (x 60). Leigh Creek, South Australia.

Fig. 4 Plagioclase and zoned fassaite (crossed nicols). (x 60). Type (c) clinker, Leigh Creek, South Australia.

Fig. 5 Thomsonite (crossed nicols) infilling gas cavity in type (a) clinker. (x 60). Leigh Creek, South Australia.

Trans. Roy. Soc. S. Aust.,
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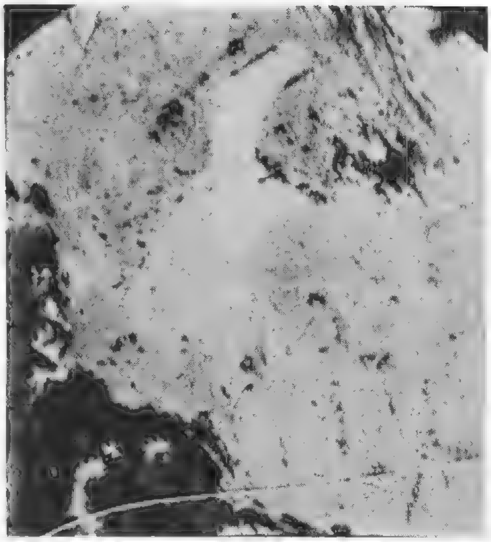


Fig. 1

Fig. 2

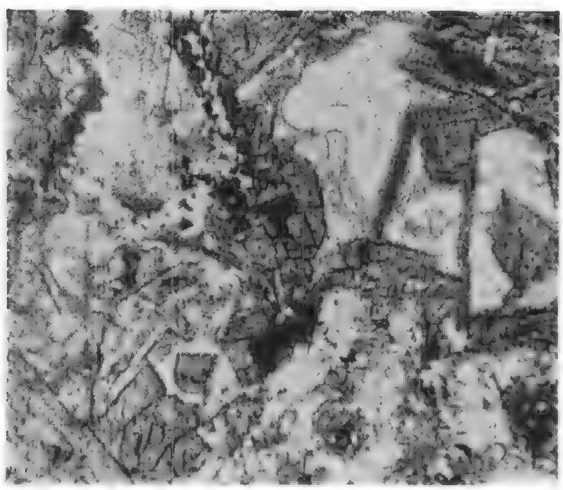
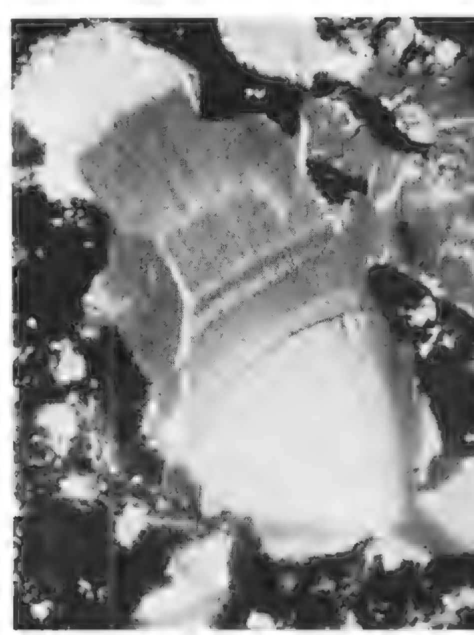


Fig. 3



NEW SPECIES AND RECORDS OF MOLLUSCA FROM SOUTH AUSTRALIA

BY BERNARD C. COTTON

Summary

In this paper a few new species of molluscs recently taken in South Australia belonging to various families are described and notes are added.

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By BERNARD C. COTTON *

[Read 17 April 1952]

594 (942)

SUMMARY

In this paper a few new species of molluscs recently taken in South Australia belonging to various families are described and notes are added.

Sphaerinova bursa sp. nov.

Shell small, oval, inflated, thin, subequilateral, a little elongate anteriorly, umbos inclined forward, concentric striae fine, periostracum shining cream to yellow, cardinal teeth rudimentary, one in the right valve, two in the left, lateral teeth weak, lamilliform. Height 8 mm., diam. 9 mm.

Loc.—River Torrens Lake (type); also in waterholes formed by creeks draining the Western Mount Lofty Ranges.

Remarks—Holotype Reg. No. D.14453, S. Aust. Museum. The species is somewhat like *S. tatiarae* but is a little more elongate anteriorly, larger, thinner, and lighter coloured. Specimens from the type locality have young shells attached to the inside of the valves. *S. tatiarae* occurs in the South-East of South Australia and at various places in the Lower Murray such as Mannum, Murray Bridge and Tailem Bend.

Australpera cara sp. nov.

Shell small unequilateral, oblique, subcordiform, tumid, anterior side slightly longer than the posterior, acuminate and sharply curved, posterior broadly rounded, ventral margin regularly curved, umbos a little prominent, forming an apical cap in young shells; concentric striae very fine, periostracum brownish, teeth as figured. Height 3 mm., diam. 4 mm.

Loc.—Brown Hill Creek, western slopes of the Mount Lofty Ranges (type); also in the River Torrens.

Remarks—The species is rare. It is smaller and less elongate than the Victorian *A. etheridgii* which occurs in the lower Murray and South-East of South Australia. Holotype Reg. No. D.14454, S. Aust. Museum.

Neotrigonia horia sp. nov.

Shell trigonal, compressed, posterior a little elongate, posterior margin truncate, straight, anterior margin rounded, ventral and posterior margin forming almost a right angle; radial ribs about thirty sharp and narrow; spiny scales weak almost obsolete in some specimens; colour pale yellow; interior pure white; hinge and teeth typical of the genus. Length 35 mm., height 30 mm.

Loc.—South Australia: Beachport 110 fms. The species ranges from 110 to 200 fms.

Remarks—It is larger than *N. bednalli,* differently shaped and coloured, the hinge teeth are weaker and set at a wider angle, the radial ribs are finer and more acute, while the sculpture is less developed. Both species occur in S.W.A. Holotype Reg. No. D.14449, S. Aust. Museum. The species bears some resemblance to the Upper Miocene *N. acuticostata* (McCoy).

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* South Australian Museum

BELCHLAMYS ATKINOS (Petterd)

Pecten atkinos Petterd 1886. Proc. Roy Soc. Tas., 329. The type came from the north-west coast of Tasmania. In the South Australian Museum Collection are the Holotype of *Pecten bednalli* Tate, Aldinga Bay, S. Aust., D.14170 and *Pecten pulleineanus* Tate 1886 South-East S. Aust., D.14171, both of which appear to be synonyms of *B. atkinos*.

MYOCHAMA ANOMIOIDES Stutchbury

Myochama anomioides Stutchbury 1830. Zool. Journ., 5, 97, pl. xlii, fig. 1-4.

Two specimens of this species were taken at Port Adelaide by R. C. Chittleborough, Zoological Department, University of Adelaide. The shells, one dark blue-grey with a yellow stripe and the other yellow mottled with faint blue and white, were attached to the carapace of a crab, *Paragrapsus gaimardii*. G. Pattison took a specimen at Glenelg attached to *Mimachlamys asperrimus*, the ribs of the scallop being neatly reproduced on the *N. anomioides* which is whitish cream coloured; also another three, dark blue-grey in colour on *Exohaliotis cyclobates* with the sculpture of that specimen even to the perforations. B. J. Weeding has two specimens attached to *Mimachlamys asperrimus* and *Mytilus planulatus*, and F. Saunders a good example, yellow coloured, attached to *Mimachlamys asperrimus* taken at Grange, South Australia. Specimens also attached to and grew on glass sheets suspended in the sea for experimental purpose at Port Adelaide. It has not been noticed by South Australian collectors in past years and is a new record for South Australia.

NOTOMYRTEA BOTANICA (Hedley)

Lucina botanica Hedley 1917. Journ. Roy. Soc. N.S.W., 51, 18. This New South Wales species was recorded by Verco 1908 from South Australia but has not been admitted in some later lists. It has been taken at numerous localities in South Australia, where shallow water examples are smoother than the deeper water dredged specimens. MacDonnell Bay, Moonta Bay, and dredged St. Francis Island 6 fms., Gulf St. Vincent 5 fms., Beachport 110 fms., 150 fms., and 200 fms.; W. Aust: King George Sound 12-14 fms., 28 fms., 35 fms.

ANAPELLA AMYGDALA (Crosse and Fischer)

Mactra amygdala Crosse and Fischer 1864. Journ. De. Conch., 12, 349, also 13, 426, pl, ix, fig. 3.

This species described from Spencer Gulf, South Australia, appears from the description to be similar to *A. adelaidae* Angas 1865, and *A. amygdala* will thus have priority.

JOUANNETIA CUMINGI (Sowerby)

Triomphalia cumingi Sowerby 1850. Proc. Zool. Soc., 1849 (1850), 161.

A small specimen of this species from the Tate Collection, said to have been taken by Tomsett at Port MacDonnell, South Australia, is in the South Australian Museum. The species was first described from the Philippines and is known to occur in North Australia and in New South Wales.

TAWERA SPISSA (Deshayes)

Venus spissa Deshayes 1835. An. S. Vert., Ed. 2, 6, 273.

Hedley 1911 recorded this species, the genotype of *Tawera* under the name *Chione mesodesma* Quoy and Gaimard 1835 from Cape Wiles, S. Aust., 100 fathoms. This was the only record of the species from South Australia until a

specimen probably representing this species was taken off Cape Donnington, 7 fathoms, by J. Veitch in April 1953. *Chione mesodesma* Quoy and Gaimard 1835 is recorded by May, 1912, as "Plentiful, as dead valves, in 100 fathoms, off Cape Pillar; wrongly identified as *C. gallinula* Lamarck."

GARI KENYONIANA (Pritchard and Gatliff)

Tellina kenyoniana Pritchard and Gatliff 1904. Proc. Roy. Vict., 17, 339, pl. xx, fig. 1-4.

This species was recorded from South Australia on the basis of two valves taken by Verco "Off Royston Head, 22 fms." A further specimen was taken in 1938 from the same locality and depth. J. Veitch of Port Lincoln has two valves in his collection dredged off Cape Donnington, 7 fathoms, 18 April 1953.

BASSETHULLIA PORCINA (Ashby)

Notoplax porcina Ashby 1912. Trans Roy. Soc. S. Aust., 43, 395, pl. xli, fig, 7, 10.

The holotype D. 12250 S. Aust. Museum, was dredged in Gulf St. Vincent and later donated by B. J. Weeding from the Torr collection. Ashby's disarticulated holotype was the only example available for study at the time. It was once thought to be a deep water form of *B. matthewsi* Pilsbry. Mr. A. K. Beasley took a further living specimen at Christie's Beach in 1937, washed up after a storm. The length is 30 mm. and the breadth 10 mm. in the dried specimen.

An examination of this second specimen which is not from deep water suggests that *B. porcina* is a distinct species.

Aviscutum veitchi sp. nov.

Shell oblong, straight parallel sides, thick, moderately elevated; sinus well marked; strongly wrinkled and pitted over the major part of the dorsum, wrinkles becoming obsolete at the margins. Diameter 40 mm. and 75 mm., height 12 mm.

Loc.—S. Aust.: Point Sinclair (type), subfossil?

Remarks—A careful examination of the holotype specimen proves that the sculpture is authentic and not due to erosion. It is placed in the genus *Aviscutum* because of the wrinkled sculpture through the parallel sides and little elevated shell are atypical features. The nearest relative appears to be *Scutus corrugatus* Reeve 1870 from Japan, but the present species is bigger and the sides are parallel. It is named after Mr. J. T. Veitch, an enthusiastic collector who specializes on the "west coast" beaches of South Australia and has made a number of interesting discoveries. Holotype Reg. No. D.14428, S. Aust. Mus. The so-called *"Scutus unguis* Linne" belonging to *Aviscutum* was recorded by Theile 1930, from Sharks Bay, West Australia.

CELLANA LATICOSTATA (Blainville)

Patella laticosatata Blainville 1825. Dict. Sci. Nat., 38, 111. This large Western Australian limpet has been found dead on the beach at Port Lincoln (Trigg), Point Sinclair (Weeding), one from Streaky Bay and in number on the Middle Recent raised beach at Port Augusta by J. Veitch. It is probably not living in South Australia and only occurs as a subfossil on the western beaches of South Australia. It is recorded from Victoria in a recent systematic list.

PHASIANELLA AUSTRALIS (Gmelin)

Buccinum australis Gmelin 1788. Syst. Nat., 3,490. On the Middle Recent stranded beach at Port Augusta, Mr. J. Veitch took a number of the Ark shell

Anadara trapezia and a series of the common *Phasianella* occurring there. The *Phasianella* is obviously related to the living *P. australis*, having a similar varied though characteristic colour pattern, but the shape is consistently and markedly different, being much more elongate and narrow. At first it was thought that the species may be more closely related to *P. dennanti* Crespin 1926 from Muddy Creek, Upper Beds, Pliocene. However, it is quite distinct from the Pliocene species, being considerably longer in the spire and having narrower whorls. This represents a remarkable change in comparative shape during a period of some few thousand years. The living species, which lives and feeds on *Cymodocea* weed, is very consistent in shape in various localities and under varying ecological conditions. A series of recent *P. australis* from Geraldton, Western Australia closely resemble the fossil. H. M. Cooper took a further specimen of the fossil *Phasianella* at one mile north of Port Augusta West and this has the characteristic colour pattern where the surface has not exfoliated. The same collector took a fossil *Hypocassis fimbriata* from a similar *Anadara* beach at about present high tide mark, opposite Flinders Bluff, ten miles south of Port Augusta West. This specimen is a miniature, two inches in length, thick, solid, with an exsert spire. The present day shell found on the nearby beach averages about three and a half inches in length and is comparatively thin with little elevation of the spire.

Dardanula flammea (Frauenfeld)

Subanaea flammea Frauenfeld 1867, Novara Exped. Moll., 12 pl. ii, fig. 18.

This has been recorded from various localities, New South Wales, Victoria and Tasmania. Mr. J. T. Veitch took it at Arno Bay, South Australia.

Rhizoconus klemae sp. nov.

Shell conical, medium size, thick, spire moderately high, apex obtuse, usually polished, blunt, white; colour golden-brown, the body-whorl white at the anterior extremity, with a medial white band interrupted by irregular nut-brown narrow axials; above the median band are three narrow spirals of alternating white and nut-brown dashes; two similar spirals below the medial band; angle of body-whorl white and nut-brown narrowly banded, a pattern which can be seen at the sutures on the spire; surface of shell polished, irregularly obscurely marked with accremental striae, slightly concavely margined below the suture. Height 47 mm., diam. 26 mm.

Loc.—S. Aust.: Corny Point (Miss M. Klem), Eyre Is., Levens (Cotton), Daly Head (Weeding).

Remarks—Hedley, November 1913, commenting on specimens sent to him by Sir Joseph Verco from St. Francis Island, South Australia, writes: "The *Conus* from St. Francis Island, South Australia, is *C. rattus* Hwass, a species common in the tropics, but I suppose a new record for your State. Your specimens agree well with a series I collected at Fitzroy Island, Queensland." Miss G. Thornley recently forwarded to me in exchange for *R. klemae* a series of *R. rattus* and two *R. taitensis* and both prove to be quite distinct from *R. klemae*.

Specimens of *R. klemae* are quite consistent in their shape and colouration. A juvenile figured here has a lighter golden colour than the adult. Shells in good condition are taken on the west coast of Yorke Peninsula, South Australia, but I have not yet seen a living specimen nor did I take it in Western Australia. Holotype D.14465 S. Aust. Museum.

Alaba coma sp. nov.

Shell thin, smooth, white except for a few reddish-brown spaced spiral and axial hair lines; whorls eight a little globose; sutures linear, aperture ovate angled at the base of the columella, outer lip thin simple, columella straight. Height 5 mm., diam. 2·8 mm.

Loc.—S. Aust.: Port Lincoln 10 fms., MacDonnell Bay, Outer Harbour; Tasm.: N. Coast; Vict.: W. Coast. Holotype Reg. No. D.14466, S. Aust. Museum.

Remarks—*A. pulchra* Adams 1862 was described from Port Adelaide and it is quite a common shell. The typical South Australian shells agree with the original description in being imbricate and validly nodosoplicate. The figure given by Hedley, Proc. Linn. Soc. N.S.W., 13, pt. 2, pl. xviii, fig. 57, does not agree with our shell, and the one in May, Illust. Index Tas. Shells, pl. xxv, fig. 22, is drawn from a North Tasmanian specimen of *A. coma*. The present species resembles *A. pulchra* in having capillary rufous spirals and axial flammules, but it is quite distinct in shape and sculpture. This may be the species formerly known under the name *A. picta* Adams, a Japanese shell. A typical specimen of the South Australian A. pulchra is figured here. Species of *Alaba* and *Diala* are frequently associated with gypsum deposits in our coastal areas.

Teretriphora mcgilpi sp. nov.

Shell sinistral, dark brown, rather obese, protoconch of three small whorls only slightly deviated from the axis and not much swollen; adult whorls six, three smooth spiral ribs, with interspaces of equal width, accremental striae fine, suture deep and narrow, dark coloured; aperture little developed, roundly rhomboidal pinched at the suture into asinus.

Loc.—Henley Beach, shell sand (McGilp).

Remarks—The species is most closely related to *Teretriphora gemmegens* Verco 1909 from Beachport, 40 fms. It differs in being much smaller, more swollen and having the spiral ribs smoother and interspaces wider. The specimen is juvenile and unique. Holotype Reg. No. D.14464, S. Aust. Museum.

Glyptorhagada umberatana sp. nov.

Shell globose-conical, fairly thick, whorls stepped, body whorl with an obsolete keel, aperture oblique, expanded margin reflected, free except where it is in contact with the base of the shell, umbilicus narrow, sculpture of oblique axial ribs. Height 19 mm., diam. 27 mm. x 23 mm.

Loc.—Umberatana, Far North of South Australia (type).

Remarks—A series of specimens of this species was taken by Mr. R. Sprigg, Department of Mines, South Australia. It is distinguished from *G. silveri* Angas in being larger, more depressed, spire more stepped and the axial sculpture is less regular and less wavy. Holotype Reg. No. D.14450.

Excellaoma pattisonae sp. nov.

Shell subconical, apex almost smooth, umbilicus nearly closed and hidden by the columella reflection, axial sculpture of distant valid riblets interspaces regularly finely axially striate; spiral lirae almost obsolete. Diam. 7 mm. x 6 mm., height 4 mm.

Loc.—National Park, Victoria Drive, Long Gully, June 1939, Mrs. D. M. Pattison, also Blackwood Road, Beaumont, and near the Commissioner's shack, National Park, June 1951 (Cotton).

Remarks—The species is most clearly allied to *E. neta* Iredale 1937 from Kangaroo Island. It differs in being larger, more conical and having well marked

scopic spirals on the protoconch. Three specimens only, one from each locality have been taken to date. The holotype, Reg. No. D.14451, S. Aust. Museum, National Park, figured and a ventral and dorsal view of the juvenile specimen from Long Gully is also given.

Pleuroxia ruga sp. nov.

Shell depressed, narrowly umbilicated, chalky white; sculpture of strong, wavy axials and close minute granules, the granules present on the earlier whorls; last whorl sharply rounded at the periphery, descending in front, wavy axial plicate on the base, aperture rounded, peristone continuous, lip expanded and free. Height 7 mm., diam. 17 mm. x 14 mm.

Loc.—W. Aust.: top of Cape Range, Exmouth Gulf (type).

Remarks—The shell is possibly related to *P. gascoynensis* Smith 1894, but I have not seen a specimen of that species, the type of which is in the British Museum. According to the description and figure of the type of *P. gascoynensis*, the present species is much larger, has a narrow umbilicus, a much coarser sculpture and more expanded lip margin. Holotype Reg. No. D.14452, S. Aust. Museum. Collected by Miss I. Crespin, Commonwealth Palaeontologist.

Conclusion

Two new species of freshwater Pelecypods and one marine Pelecypod are described and notes of seven others are added. Four new species of marine Gastropod are introduced and three others are discussed. Three new species of native land shells are described.

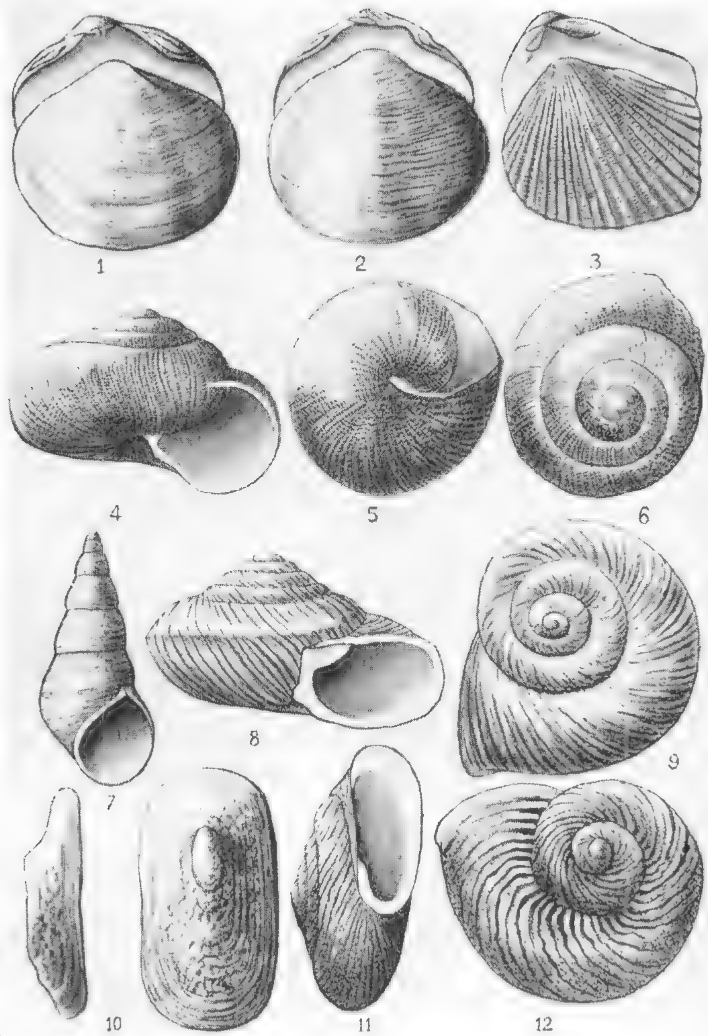

Fig.

1	Sphaerinova bursa sp. nov.
2	Australpera cara sp. nov.
3	Neotrigonia horia sp. nov.
4	Excellaoma pattisonae sp. nov.
5, 6	" " juveniles
7	Phasianella australis, variety
8, 9	Glyptorhagada umberatana sp. nov.
10	Aviscutum veitchi sp. nov.
11, 12	Pleuroxia ruga sp. nov.

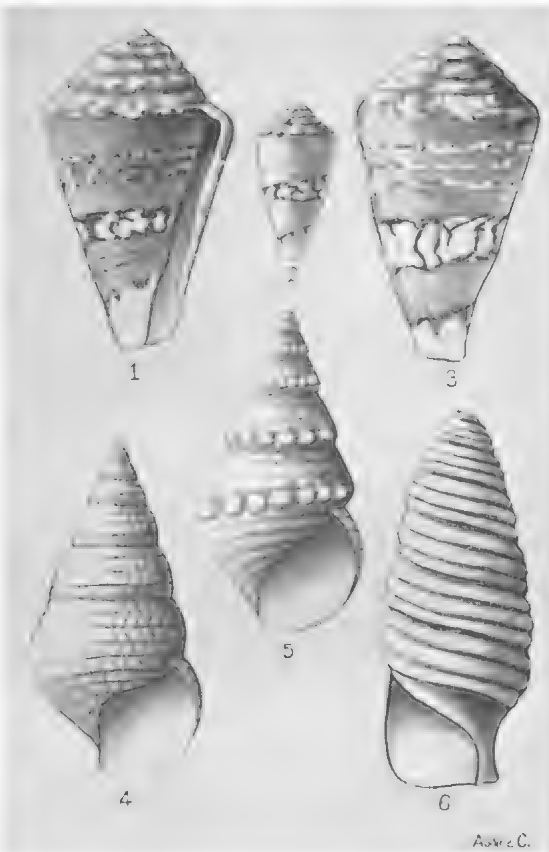

Fig.
1 Rhizoconus klemae sp. nov. ventral view, holotype
2 Rhizoconus klemae sp. nov. juvenile
3 Rhizoconus klemae sp. nov. dorsal view, holotype
4 Alaba coma sp. nov. holotype
5 Alaba pulchra Adams
6 Teretriphora mcgilpi sp. nov. holotype

NATURAL SINTERS FROM MT. REMARKABLE AND TEMPE DOWNS

BY GEORGE BAKER

Summary

Specimens of clinker-like material from Mt. Remarkable in South Australia and Tempe Downs in Central Australia are described. Evidence is advanced to indicate that the clinker-like masses are natural partially sintered products of surface sandy soils, possibly developed by the heating action of lightning.

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By George Baker*

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Specimens of clinker-like material from Mt. Remarkable in South Australia and Tempe Downs in Central Australia are described. Evidence is advanced to indicate that the clinker-like masses are natural partially sintered products of surface sandy soils, possibly developed by the heating action of lightning.

INTRODUCTION

Specimens of naturally sintered products have been discovered at different times in widely separated localities in Australia. The term "sinter" is used broadly in the sense that sinter is a partially fused clinker-like product devoid of fluxing materials.

Natural sinter from Mt. Remarkable (3,178 ft.) was found near the summit by Mr. R. G. Thomas in 1937. Mt. Remarkable is near Melrose, approximately 25 miles N.N.E. of Port Pirie on the eastern side of Spencer Gulf, South Australia. The rock composing Mt. Remarkable is a quartzitic (91% SiO_2) member of the Adelaide Series (Proterozoic). The main mass of sinter, approximately two cubic feet in volume, rested on a thin bed of soil. Smaller fragments were scattered over an area of several square yards and their weathered appearance indicated they were not very recent in origin. Mr. Thomas collected about one cubic foot of the material; several of the least weathered fragments, totalling 218 grams, were examined by the author.

Natural sinter from Tempe Downs was found on top of a hill on the Tempe Downs stock station in Central Australia. Tempe Downs is 120 miles W.S.W. of Alice Springs and approximately 40 miles south of the western end of the MacDonnell Ranges. The sinter, handed by the manager of Tempe Downs stock station to Mr. H. Finlayson of Adelaide, was passed on to Mr. R. G. Thomas in 1937. It had previously been exhibited at the Royal Society of South Australia as possibly being a meteorite. The sinter occurred on the surface in an area composed of quartzites and sandstones of Larapintine (Ordovician) age. As received by the author for examination, the Tempe Downs sinter consisted of one piece weighing 204 grams. It evidently formed portion of a larger mass, but was the only piece originally acquired.

DESCRIPTION OF SPECIMENS

Mt. Remarkable Natural Sinter

The sample (pl. IV A) consists of several irregular lumps of scoriaceous sinter ranging in size from 1" x ¾" to 3" x 2¼". Surfaces are irregular, partly smooth and ropy, partly rough and finely cellular from honeycombing with vesicles. The colour on external surfaces is greyish-to yellowish-and reddish-brown. Unweathered freshly fractured areas are dark-grey and vitreous with occasional quartz grains and brownish patches richer in fused iron compounds.

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Microscope sections reveal rounded quartz grains up to 0·6 mm. across and averaging 0·4 mm., embedded in a matrix of light-to dark-brown, rarely colourless, vesicular glass. Many of the quartz grains are cracked, several have been granulated and show strain polarisation. Apatite prisms, included in the quartz, account for much of the P_2O_5 content (Table I, column I). Lechatelierite particles in the glass are rare and minute. There are no other unfused grains besides quartz, unless some of the granulated grains represent original fine-grained quartzite. Evidently the material was held at fusion temperature long enough to fuse everything except quartz, but not long enough to fuse all the quartz grains; the lechatelierite particles represent the last remnants of incompletely fused crystalline silica.

The rounded character of the quartz grains is ascribed to the effects of fusion largely, but may have been initially developed by weathering prior to fusion. Several of the quartz grains are surrounded by narrow zones of clear completely isotropic glass (R.I. = 1·525). These zones are usually sharply demarked from the anisotropic unfused portions of the quartz grains and the surrounding isotropic brown glass (R.I. = 1·545), but some zones merge from colourless, through pale yellowish-brown (R.I. = 1·540), to dark-brown glass. Occasional opaque areas in the glass are composed of felted masses of minute fibres, associated with numerous small particles of hydrous iron oxide. The fibres have low birefringence, low refractive index and oblique extinction up to 30°, but are too minute for accurate determination.

A polished surface of the sinter reveals skeletal crystals and small cubes of magnetite. Sulphides are rare and largely confined to unfused quartz remnants, but rare globules of pyrite also appear in the glass.

Tempe Downs Natural Sinter

The hand specimen (pl. IV B) is externally very similar to the Mt. Remarkable sinter and is an irregularly shaped lump measuring $3\frac{1}{4}'' \times 2\frac{3}{4}'' \times 1\frac{1}{2}''$ to 2″. It is scoriaceous, with parts showing rounded glassy protuberances and a colour variation from greyish-to yellowish-and reddish-brown. Parts of the surface are ropy, a fine rippled structure on some of the ropy portions representing finer flow structures. Fracture surfaces are vesicular, with numerous pits ranging in diameter from 13 x 8 mm. to under 0·5 mm. An unusual phenomenon encountered on breaking off portion of the specimen was the exposure of a small complete bubble of glass in a cavity measuring 5 x 4 mm. The glass bubble measured 1·5 mm. across and was fed by a small bubble pit 0·5 mm. across, situated on the cavity wall. The glass in the bubble walls is 0·004 mm. thick and contains occasional, minute drawn-out gas bubbles.

The more glassy portions of the interior of the sinter resemble freshly broken fragments of fulgurites, secondary mineral matter being absent from the vesicles. Portions with visible quartz grains embedded in the glass resemble finely vesicular acidic lava.

Microscope sections of the Tempe Downs sinter reveal a large number of rounded and sub-angular quartz grains embedded in vesicular glass discoloured by iron oxides. The quartz grains range up to 0·5 mm. across and average 0·2 mm., being smaller but more numerous than in the Mt. Remarkable sinter and with less glass. The proportion of glass to unfused quartz is 25 : 75 for the Tempe Downs specimen, 70 : 30 for the Mt. Remarkable specimen.

The glass is colourless to pale yellowish-green in section, zones of colourless glass (R.I. = 1·525) occurring around partially fused quartz grains as in the Mt. Remarkable specimens, but areas of brownish coloured glass are not as abundant, although they have the same refractive index (1·545).

Minute bubbles are common in the glass. Microscopic aggregates of capillary crystals radiate outwards into the glass from the walls of some of the gas cavities. They are low polarising, greyish-brown in colour, but too fine for accurate determination; they are possibly related to mullite. The fact that the glass is not very abundant and is frequently opaque from dense concentrations of minute inclusions, prevents an assessment of the distribution of lechatelierite particles in the glass. The only other detrital grains preserved in the glass, besides quartz, are rare grains of zircon unaffected by the heating process.

A polished surface of the Tempe Downs sinter reveals minute rounded globules of pyrite that are common in the glass, but rare in the unfused quartz grains. These globules range in size from under 0·001 mm. to 0·008 mm. and are scattered at random throughout the glass. Rare small crystals of magnetite average 0·020 mm. and are seldom as large as 0·080 mm. Minute skeletal crystals of magnetite are also present. Small globules of pyrite are occasionally included in the magnetite. Where exposed on the walls of gas cavities, some of the pyrite globules have been oxidized to form thin crusts of limonite. The occasional darker-coloured patches in the glass prove to be flecked with minute plates of hematite on examination under the ore microscope.

CHEMICAL ANALYSES

Chemical analyses of the Mt. Remarkable and Tempe Downs natural sinters have been carried out in the chemical laboratory of the Mineragraphic Investigations Section, Commonwealth Scientific and Industrial Research Organization, with the following results (Table I).

TABLE I

I. Mt. Remarkable natural sinter, South Australia (anal. G. C. Carlos).
II. Tempe Downs natural sinter, Central Australia (anal. G. C. Carlos).

	I	II		I	II
SiO_2	63·54	76·08	H_2O (–)	0·04	0·03
Al_2O_3	18·59	10·27	CO_2	nil	nil
Fe_2O_3	1·56	1·67	TiO_2	0·61	0·78
FeO	3·48	2·59	P_2O_5	1·61	0·31
MgO	1·50	1·83	MnO	0·18	0·08
CaO	5·94	3·05	C	nil	nil
Na_2O	0·61	0·77	Cl_2	nil	nil
K_2O	2·20	2·34	SO_3	nil	nil
H_2O (+)	0·16	0·23			
			Total	100·02	100·03

Neither nickel nor chromium was detected in either of the two analyses set out in Table I.

The differences between analyses of the Mt. Remarkable and Tempe Downs natural sinters reflect variations in the chemical character of the source materials and hence variations in their original mineral content. Both types were evidently derived largely, if not entirely, from inorganic materials. The Tempe Downs sinter was derived from the soils produced on a quartzitic rock richer in SiO_2, but containing less felspathic material and less of a P_2O_5-bearing mineral (or less soil phosphates) than the Mt. Remarkable sinter. In the remaining ingredients, however, the two source materials were chemically and mineralogically very similar.

COMPARISON OF THE SINTERS WITH OTHER NATURALLY FUSED PRODUCTS

The two samples of natural clinker closely resemble one another in appearance, but whereas the Tempe Downs sinter is essentially a mass of small adhering quartz grains, bound together into a coherent mass by a matrix of glass, often with only very thin films separating adjacent grains, the Mt. Remarkable sinter has wider areas of glassy matrix throughout, with larger quartz grains scattered through the glass. Cristobalite, which occurs in Libyan Glass (Spencer, 1939) and tridymite, which occurs in some fulgurites (Baker and Gaskin, 1946), have not been observed in the glass of either sinter sample.

There seems to be little in common between these two natural sinters and other known products of natural fusion such as clinker from the fusion of coal ash, impactites, Libyan silica glass, etc., but the more glassy portions of the sinters do show some resemblance to Macedon Glass and certain pieces of Darwin Glass (Queenstownites). Inasmuch as the sinters are not as highly fused as Macedon Glass and Darwin Glass, they were evidently subjected to a more transient heating process.

TABLE II

Location	Colour of hand Specimen	R.I. of glass	Density of Specimen	% Silica in Specimen	Reference
Henbury, Central Australia	black	1·545	2·31	68·88	Spencer (1933)
Mt. Remarkable, South Australia	dark - grey to yellowish - and reddish - brown	1·525 1·545	2·57	63·54	
Tempe Downs, Central Australia	dark - grey to yellowish - and reddish - brown	1·525 1·545	2·54	76·08	
Wabar, Arabia	black	1·500	2·24	87·45	Spencer (1933)
Darwin, Tasmania	pale greenish - grey	1·497	-	87·00	David, Summers and Ampt (1927)
Macedon, Victoria	dark - grey	1·490	2·08	-	Baker and Gaskin (1946)
Darwin, Tasmania	smoky - grey	1·486	2·296	86·34	David, Summers and Ampt (1927)
Macedon, Victoria	pale greenish - grey	1·485	1·94	-	Baker and Gaskin (1946)
Wabar, Arabia	white	1·468	2·10	92·88	Spencer (1933)
Libya, North Africa	pale yellowish - green	1·462	2·206	97·58	Clayton and Spencer (1934)
Barringer Meteor		1·458	2·10	-	Rogers (1930) and Spencer (1939)
Crater, Arizona	white	1·460	2·21		

In Table II, some of the properties of various described naturally fused products are listed with those from Tempe Downs and Mt. Remarkable for purposes of comparison. The table has been arranged in order of decreasing

refractive index values and shows that there is a general decrease in densities and increases in silica contents as the refractive index decreases in value (cf. Spencer, 1939, p. 430). The refractive index values of the Mt. Remarkable and Tempe Downs sinters were determined by the immersion method and refer to glassy portions only, while the densities and silica contents are those of the complete samples of the sinters, representing glass and other ingredients.

The Mt. Remarkable and Tempe Downs sinters had not commenced to fuse at 1,200°C, thus reflecting their predominantly siliceous composition. The densities of these two samples were determined on material in the powdered form at 20°C.

ORIGIN OF THE SINTERS

The natural sinters from Mt. Remarkable and Tempe Downs were evidently derived wholly from inorganic matter. The scoriaceous appearance of the Mt. Remarkable sinter is very similar to that of the Tempe Downs sinter and thin sections reveal similar relationships in each sinter between unfused quartz grains and the glass in which they are embedded. Therefore there seems to be no doubt that the origin of both sinters was essentially the same, formation resulting from partial fusion in the absence of fluxes, of comparable inorganic materials, presumably by means of a similar heating agent. Fusion in each sinter was evidently due to a source of heat of high temperature and short duration, followed by rapid cooling. Because of its greater content of glass, the Mt. Remarkable material was presumably heated for a slightly longer period.

In the absence of sufficient confirmatory evidence no conclusive opinion can be reached concerning the source of heat responsible for fusing natural materials and generating natural sinter, natural clinker, natural slag and natural silica glass. Detailed petrological, mineralogical, chemical and spectrochemical investigations often provide conclusive evidence of the original nature of the source materials, but fail to reveal the true nature of the source of heat. From the physical standpoint it is to be expected that the fusion of terrestrial materials on the surface of the earth to form natural sinter, clinker, slag and glass, requires high temperatures and sometimes the presence of fluxes.

The known geological evidence, supported by chemical evidence and certain physical characteristics of the natural sinters, bears out the conclusion that the Mt. Remarkable and Tempe Downs natural sinters are non-volcanic, non-meteoritic, not due to the burning of coal seams or tree trunks and not due to bush or grass fires, (cf. Baker and Gaskin, 1946). The fused products are certainly not artificial and are in no way allied to extra-terrestrial glasses like the tektites. In the absence of evidence of any other kind, eliminating most of the known natural heating agents, recourse is made to natural electrical discharges as the probable cause of fusion. However, the conventional tubular shape of the well-known fulgurites is lacking in the Mt. Remarkable and Tempe Downs sinters and they are neither as acidic nor as vitrified as the "lightning tubes." Moreover, they have a much greater diameter than that (5 cm.) set out by Schonland (1932, p. 93) as the typical diameter for fulgurites. Hence, a greater spread of the heating agent than in the limited confines producing fulgurites, is required for the development of the two sinter samples under consideration. The fact that fusion of the sinters was only partial, while that of the true fulgurites is virtually complete, indicates that temperatures were generally lower than in the formation of "lightning tubes," and the lumpy character of the sinters compared with the narrow

tubular shape of fulgurites, suggests that the momentarily applied heat was not quite as confined in its effect on the soil at centres of lightning strike.

It is conceivable that an agency such as ball lightning could supply the momentarily applied heat at the lower temperatures that would suffice to form the partially vitrified products (sinters) from sandy soils. Although the phenomenon of ball lightning may not yet be universally accepted, it has been shown that fireballs undoubtedly do become generated under certain conditions, but their characteristics are not fully understood. Brand (1923), Wolf (1943), Jensen (1933) and others record several authentic observations of ball lightning, but note that it is rare and thus difficult to study systematically. Kuhn (1951) has recently photographed an example of ball lightning, while Jensen (1933) illustrates several photographs of fireballs having diameters of 28 feet and 42 feet respectively. Jensen (1933, p. 374) found that ball lightning most frequently occurred in connection with dust-laden air, as in a wind squall or tornado.

Since there is no conclusive evidence to prove that ball lightning was responsible for the generation of the Mt. Remarkable and Tempe Downs sinters, an origin due to this particular type of lightning discharge cannot be specifically invoked. The suggestion is advanced, however, that in the absence of evidence indicating any other agency or other type of lightning discharge, there is a strong likelihood of ball lightning being responsible for the sintering of sandy soils. That the earthing of some sort of lightning was responsible for the formation of the sinters, is somewhat strengthened by the fact that both of the samples of sinter occurred on hilltops. It would be of interest to know if any other sinters of similar nature also occur preferentially on hilltops.

Summarising the evidence that indicates a possible lightning mode of origin and eliminates other agents as the source of heat, it is found that:—

(i) lightning in its known forms can supply the degree of heat required for the partial fusion of sandy soils,
(ii) the partially fused products are both from hilltops,
(iii) nickel and chromium are absent from the sinters, and evidence for the local fall of meteorites is not to hand,
(iv) there is neither chemical nor mineralogical resemblance to fused coal-ash and no coal seams occur in the neighbourhood,
(v) carbon and wood-ash are absent, there are no chemical affinities with "straw silica glass" or allied products such as slag from charcoal, and the sinters fuse in the laboratory at much greater temperatures than do the products from wood-ash or coal-ash fusion,
(vi) there are no affinities with tektites,
(vii) the sinters are not artificial products and they are not products of terrestrial volcanoes.

ACKNOWLEDGMENTS

The author is indebted to Mr. R. G. Thomas for the samples and field notes relating to the Mt. Remarkable and Tempe Downs sinters and for critical revision of the manuscript. Thanks are also due to Dr. F. Loewe of the Meteorology Department, University of Melbourne, for helpful discussions on the nature and effects of lightning, and to Mr. G. C. Carlos for the photographs.

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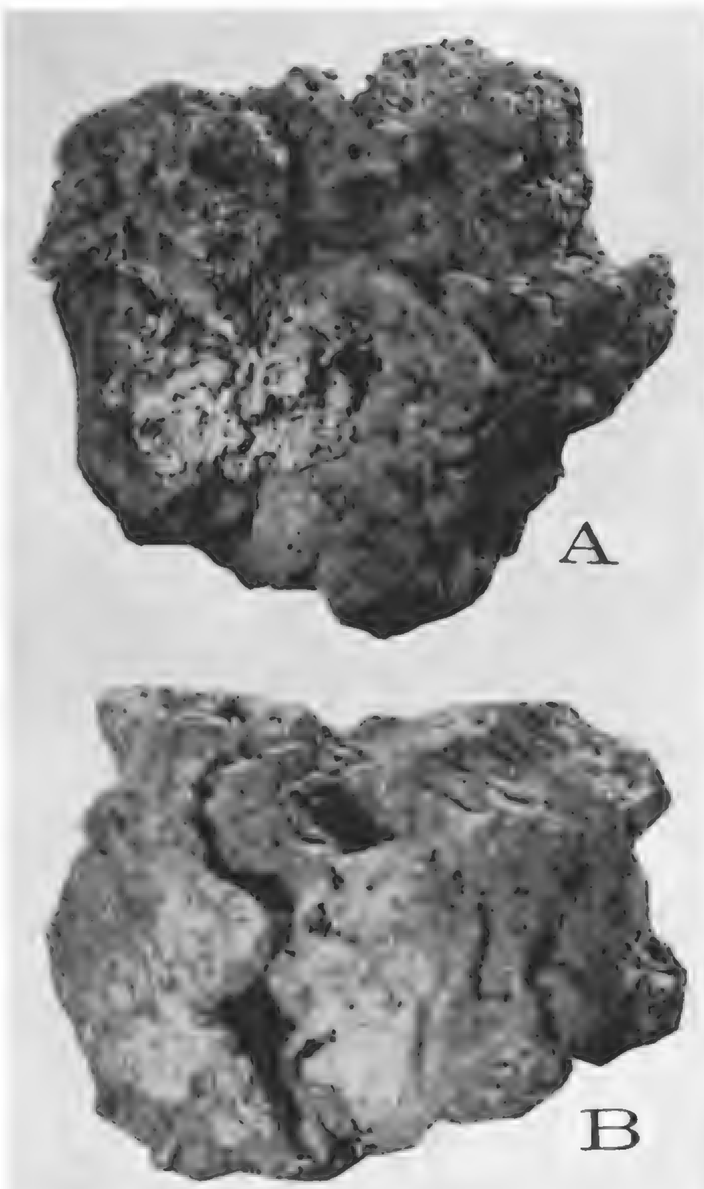

A. Sinter from near summit of Mt. Remarkable, South Australia (nat. size). Fragment showing scoriaceous character.

B. Sinter from hilltop on Tempe Downs stock station, Central Australia (nat. size). Fragment showing scoriaceous and ropy character.

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SOME MARINE FREELIVING NEMATODES FROM THE AUSTRALIAN COAST

BY PATRICIA M. MAWSON

Summary

The following nematodes have been identified from dredgings off the coast of New South Wales (locality indicated as N.S.W.), form St. Vincent Gulf (Port Willunga and Port River), and from Pennington Bay, Kangaroo Island (Penn. B.) : — Anticomopsis jibbonensis n. sp. (N.S.W.); Thoracostoma australe n. sp. (N.S.W.); Enoplus meridionalis Steiner (Port Willunga); Metoncholaimus pristiurus Z. Strassen (Pt. River); Pontonema hackingensis n. sp. (N.S.W.); Symplocostoma longicolle Bastian (Penn. B.); Symplocostomella johnstoni n. sp. (N.S.W.); Mesacanthion gracilisetosus Allgen (N.S.W.); Harveyjohnstonia kartanum n.g., n.sp. (Penn. B.)

SOME MARINE FREELIVING NEMATODES FROM THE AUSTRALIAN COAST

By Patricia M. Mawson *

[Read 12 June 1952]

595.132 (210.5) (94)

Summary

The following nematodes have been identified from dredgings off the coast of New South Wales (locality indicated as N.S.W.), from St. Vincent Gulf (Port Willunga and Port River), and from Pennington Bay, Kangaroo Island (Penn. B.) :—

Anticomopsis jibbonensis n. sp. (N.S.W.); *Thoracostoma australe* n. sp. (N.SW.); *Enoplus meridionalis* Steiner (Port Willunga); *Metoncholaimus pristiurus* Z. Strassen (Pt. River); *Pontonema hackingensis* n. sp. (N.S.W.); *Symplocostoma longicolle* Bastian (Penn. B.); *Symplocostomella johnstoni* n. sp. (N.S.W.); *Mesacanthion gracilisetosus* Allgen (N.S.W.); *Harveyjohnstonia kartanum* n. g., n. sp. (Penn. B.).

The work done on Australian freeliving nematodes up to the present has been summarised by the late Professor Harvey Johnston in his Census of 1938.

The subject matter of this paper was recommended to the author by Professor Johnston a short time before his death. Unfortunately he was unable to read the manuscript, so the classification used and conclusions reached are the author's sole responsibility. The labour of identification was greatly lightened by the use of Professor Johnston's personally compiled septemmatic catalogue on nematodes as well as his catalogue of authors. It is with gratitude to Professor Johnston and his family that we acknowledge the gift of this valuable collection to the University of Adelaide.

The material examined comprised three collections.

(1) from dredgings off the New South Wales coast by the C.S.I.R.O. Research Vessel "Warreen"; this collection was kindly forwarded to us by Mr. K. Sheard of the Fisheries Division;

(2) littoral forms collected in St. Vincent Gulf by Professor Johnston; and

(3) littoral forms collected at Pennington Bay, Kangaroo Island, by my colleague, Mr. S. J. Edmonds.These were present in surface scrapings from the rock around a sandy pool, where there was very little vegetation.

Anticomopsis gibbonensis n. sp.

Fig. 1-2

Four males and one female were taken from a collection dredged five miles east of Port Gibbon, New South Wales. They are long slender worms tapering in the oesophagial region; the tail is conical, ending in a suddenly narrowed tip. The cuticle is smooth, somatic setae few and scattered. The head bears three well-defined lips. Six cephalic papillae surround the mouth and ten cephalic setae lie on a ring 15μ behind the anterior end, the setae being to 20μ long, *i.e.*, two-fifths of the width of the head at that level. The amphid is indistinct. Cervical setae in two groups of four in each lie 50μ from head end. Buccal capsule absent. Oesophagus of even diameter throughout, at its posterior end its width is about one-ninth that of body at same level.

No ripe eggs are present in the female. The ovaries are divergent and reflexed.

* University of Adelaide

The male tail and spicules are of the typical form in the genus.

♀ : L = 10·3 mm. $\alpha = 43$, $\beta = 7{\cdot}3$; $\gamma = 50$

Cobb: $\dfrac{—;\ 4{\cdot}5;\ 13{\cdot}6;\ 58{\cdot}2;\ 98}{—;\ 1{\cdot}0;\ \ 2{\cdot}2;\ \ 2{\cdot}3;\ {\cdot}97} = 10{\cdot}3$

♂ : L = 10·3 mm. (9·8—11·2); $\alpha = 50$, $\beta = 6$; $\gamma = 45$.

Cobb: $\dfrac{—;\ 4{\cdot}2;\ 16{\cdot}6;\ \mathrm{M};\ 98}{—;\ 1{\cdot}0;\ \ 1{\cdot}8;\ 2{\cdot}0;\ 1{\cdot}2} = 10{\cdot}3$

This species differs from *A. typicus* Micol., in the position of the vulva, the α, β and γ proportions, and in the total length of the worms.

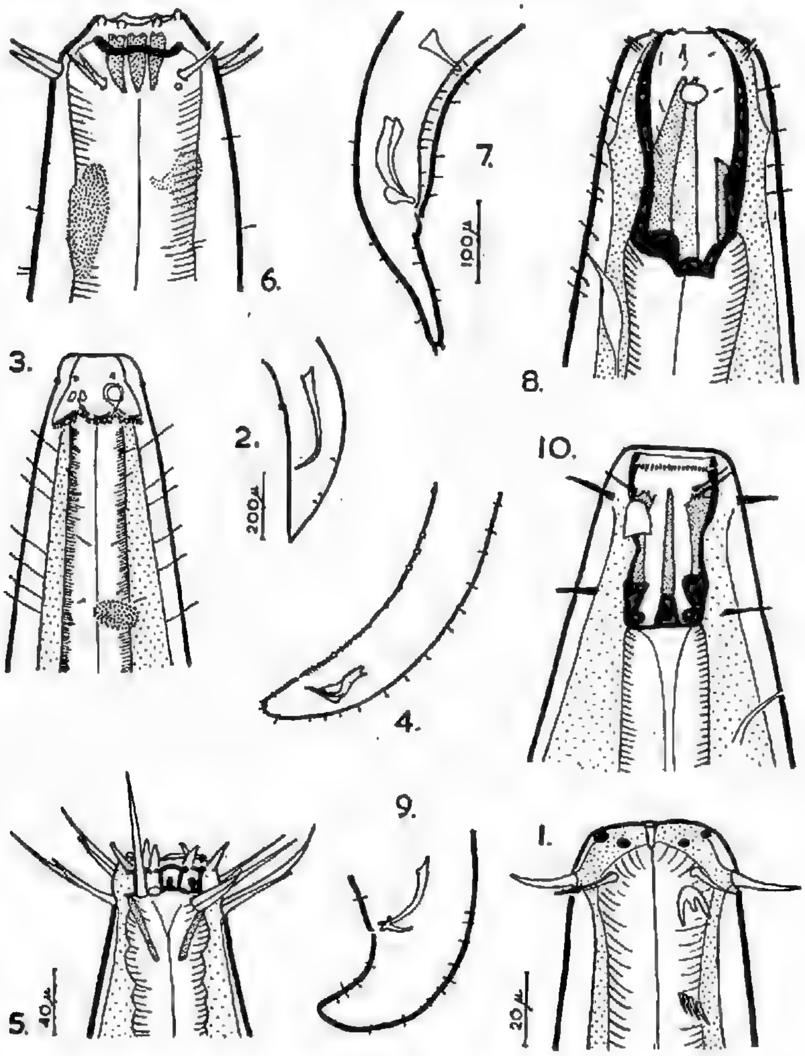

Fig. 1-10

Fig. 1-2, *Anticomopsis gibbonensis:* 1, head of male; 2, male tail. Fig. 3-4, *Thoracostoma australe:* 3, head; 4, male tail. Fig. 5, *Mesacanthion gracilisetosus:* head. Fig. 6-7, *Enoplus communis,* var. *meridionalis:* 6, head; 7, male tail. Fig. 8-9, *Pontonema hackingensis:* 8, head; 9, male tail. Fig. 10, *Symplocostomella johnstoni:* head. Fig. 1, 6, and 10 to same scale; fig. 3, 5, and 8; fig. 4, 7, 9.

Thoracostoma australe n. sp.

Fig. 3-4

This species was taken from three dredging stations off New South Wales coast: (1) 5 miles east of Port Gibbon; (2) 4 miles off Port Hacking, at 80 M.; (3) off Wata Muri at 75 M.

Relatively large worms, tapering in oesophageal region, rest of body almost cylindrical; tail short and rounded. Diameter at level of short cephalic setae is 47-50μ, at level of ocelli 90-100μ, at nerve ring ·15-·17 mm., at base of oesophagus ·2-·23 mm., and at widest part of body ·23-·27 mm.

Cephalic armature is more or less imperforate except near posterior edge where slit-like pores appear irregularly parallel to the margin. Just posterior to the margin is a row of small refractive bodies as described by Ditlevsen for *T. campbelli*. The ocelli are ·15-·2 mm., and the nerve ring ·65-·7 mm. from the head. The oesophagus widens slightly for the posterior third of its length.

Male—Spicules are ·23 mm. long, gubernaculum 80μ long. Tail at anus is as wide as its length, ·14-·16 mm. On male tail are five pairs of adanal setae, and six pairs of subterminal, as well as irregular dorsal setae. Preanally are two rows of numerous setae, which are more scattered as distance from anus increases; about ·1 mm. in front of anus is a well-developed median preanal papillate organ and anterior to this eight pairs of papillae, successively less well developed.

Female—Vulva is just posterior to mid-length of body, 53-58% of body length from head. At most there are three ova to each oviduct. In 12·5 mm. worm, $G1 = 15{\cdot}2\% + (8{\cdot}5\%)$, $G2 = 19{\cdot}2\% + (10{\cdot}4\%)$. Well-developed ova are 700μ by 200μ. In the female the tail is sometimes slightly longer than the anal width.

♀ : $L = 12{\cdot}5\text{-}17$ mm.; $\alpha = 54{\cdot}3\text{-}63$; $\beta = 6 - 7{\cdot}1$; $\gamma = 63 - 69{\cdot}9$
$V = 51\text{-}54\%$

♂ : $L = 11{\cdot}8 - 15{\cdot}4$ mm.; $\alpha = 51{\cdot}3\text{-}56{\cdot}3$; $\beta = 5{\cdot}9\text{-}6{\cdot}3$; $\gamma = 90{\cdot}8\text{-}96$

This species is close to *T. campbelli* Ditlevsen in the structure of the cephalic helmet. It differs in the position of the vulva, the shape of the oesophagus, and the position of the eyes.

Mesacanthion gracilisetosus Allgen 1930

(Fig. 5)

Two female specimens, one very immature, referable to *Mesacanthion graciIeselosus* Allgen, were taken from 75 M. off Wata Muri, New South Wales coast.

$L = 4{\cdot}6$ mm.; $\alpha = 36{\cdot}6$; $\beta = 4{\cdot}6$; $\gamma = 11{\cdot}5$; A-V = 54%

The measurements and general description agree with that of Allgen 1930 (p. 189-191) of male and females from Macquarie Island.

Enoplus communis var. meridionalis Steiner 1921

(Fig. 6-7)

From rock scrapings in sublittoral fringe, Port Willunga, South Australia. Material consists of two males, two females and five juveniles. The proportions given below and appearance agree with Steiner's account of *E. communis* var. *meridionalis*. They differ from *E. communis* Eberth in (1) body length; (2) α and γ values; (3) relation between length of spicules and distance between cloaca and accessory organ. The body diameter is relatively greater than that given by Steiner; a low α value, however, has been recorded by Chitwood (1936) for the sub-species.

♂ : L = 2·3-2·5 mm.; $\alpha = 18{\cdot}5$; $\beta = 6$; $\gamma = 14$
♀ : L = 2·4-2·6 mm.; $\alpha = 16$; $\beta = 6$; $\gamma = 12{\cdot}5$; V: 57·7-58·3%
Juv.: L = 1·1-1·8 mm.

The position of this subspecies has been somewhat confused by Stekhoven, by whom it was stated in 1933 (Coninck and Stekhoven, p. 32) to be a synonym of *E. striatus* Eberth, but in 1950 (p. 337) and 1943 (p. 49) given specific status. In his redescription of *E. meridionalis* from material collected in Villefranche, Stekhoven describes the male accessory organ as tubular, lying "immediately" in front of the proximal end of the spicule. Steiner describes and figures a trumpet-shaped accessory organ which lies some distance in front of proximal end of spicule. Measured on his figure it is one and a half time spicule length from anus. In addition, the median ventral papilla at mid-length of the "tail," described as outstanding by Steiner, is not figured or mentioned by Stekhoven. It is obvious that Stekhoven's material is not *E. meridionalis* Steiner.

Chitwood (1936, 208) recorded the subspecies from Beaufort, U.S.A.; in his figures, the accessory piece, somewhat enlarged at its proximal end, lies one and a half times the spicule length in front of the anus; in addition he figures a median ventral prominence on the tail at about its mid-length. Allgen (1947, 101) recorded the species from California; his figure shows a trumpet-shaped accessory piece one and three-quarter times the spicule length in front of the anus.

Eberth's work of 1863 being inaccessible, the present author is unable to compare the South Australian material with *E. striatus*.

METONCHOLAIMUS PRISTIURUS (Z. Strassen)

This species is apparently common in the Port River; many specimens were taken from mud near the Jervois Bridge, and the species appears on experimental subtidal plates at a station nearby. Our specimens agree in morphology with the description given by Cobb 1932, and with that of Stekhoven and Adam (1931, 23-24) (for *M. denticaudatus* S. and A., which Coninck and Stekhoven (1933-55) recognise as a synonym of *M. pristiurus*).

The measurements presented in formulae in the two papers differ very slightly and those given below for the South Australian specimens are close to them, though the oesophagus is apparently rather shorter.

According to Cobb, stagnant marine mud is a common habitat for the species.

♂ : L = 5·8-6·5 mm.; $\alpha = 61$; $\beta = 10{\cdot}9$; $\gamma = 26{\cdot}2$

Cobb:
$$\frac{0{\cdot}58 \qquad 0{\cdot}47 \qquad 9{\cdot}4 \qquad M \qquad 96{\cdot}1}{0{\cdot}7 \qquad 1{\cdot}2 \qquad 1{\cdot}3 \qquad 1{\cdot}6 \qquad 0{\cdot}7} = 6{\cdot}03 \text{ mm.}$$

♀ : L = 6·1-6·5 mm.; $\alpha = 63$; $\beta = 11{\cdot}5$; $\gamma = 25{\cdot}2$; Vulva: 70·9%

Cobb:
$$\frac{0{\cdot}6 \qquad ? \qquad 9{\cdot}4 \qquad 70{\cdot}9 \qquad 91{\cdot}2 \text{ (d M pore)} \qquad 96{\cdot}0}{0{\cdot}7 \qquad ? \qquad 1{\cdot}3 \qquad 1{\cdot}4 \qquad — \qquad 0{\cdot}7} = 6{\cdot}3$$

Pontonema hackingi n. sp.

(Fig. 8-9)

Four specimens, three females and one male, were in two collections taken off Port Hacking.

♀ : L = 8·7-11 mm.; $\alpha = 35\text{-}35{\cdot}5$; $\beta = 6{\cdot}7\text{-}8$; $\gamma = 58$; A-V = 56·3-57%
♂ : L = 11·3 mm.; $\alpha = 36{\cdot}4$ $\beta = 8$; $\gamma = 66{\cdot}4$

Cuticle with numerous short setae, arranged roughly in six rows. Ten caphalic setae, about one-eighth to one-ninth head width. Six small oral papillae.

Buccal capsule about half as wide as long, $60\mu \times 120-130\mu$, heavily chitinised, slightly wider anteriorly in dorso-ventral direction. Ventral teeth reach a point 26μ from anterior end of buccal capsule, i.e., three-quarter length of buccal capsule from its floor. The small almost circular amphid, one-seventh diameter of head at that level, lies at about the level of the tips of subventral teeth.

Oesophagus cylindrical; nerve ring ·5-·57 mm. from anterior end of worm. Excretory pore just posterior to buccal capsule.

Female—Vulva just behind midbody; eggs, with their shell, $200\mu \times 250\mu$.

Male—Spicules 130μ long, acicular, equal in length to anal breadth; gubernaculum 55μ long, with paired anterior projections near tip. Several pairs of ventral papillae preanally, from ·15 mm. in front of anus to about ·5 mm. in front.

The species lies close to *P. papilliferus* (Filipjev), differing mainly in the length of the male tail and in the absence of a preanal cushion of setae.

Symplocostomella johnstoni n.sp.

Fig. 10

Taken in trawl at (?200 M) 5 miles east of Point Gibbon on New South Wales coast near Port Hacking. Only two females present, one ovigerous; their lengths are 8·6 mm. and 10·1 mm. respectively. Measurements given below are of the latter, although the submedian view of head in fig. 12 is of the younger female

L: 10·1 mm.; $\alpha = 3{\cdot}7$; $\beta = 7$; $\gamma = 33{\cdot}6$. Vulva = 58·5%.

Head truncated; ten large setae, all 15μ long, lie 11μ behind the anterior end. Amphids lie directly behind lateral setae, their diameter one-sixth diameter of head at that level.

Buccal capsule is 46μ deep, its internal diameter varying slightly at different levels, generally about 20μ. One subventral tooth, larger than the others, is stout and poined, and arises from the base of the buccal capsule, against the wall; the other two teeth are more slightly built, and each arises from a "cushion" projecting from the lower part of the buccal capsule wall. These two teeth project into the cavity as slender outgrowths terminating in widened serrated ends.

The excretory pore lies shortly behind the buccal capsule, 60μ from the anterior end. The oesophagus widens in its second half. The cuticle anteriorly bears scattered long thin setae.

The tail is ·3 mm. long, its posterior half cylindrical. Width at anus is ·1 mm.

Vulva is very insignificant, just posterior to midbody. The eggs in the uteri are probably not "ripe" as they do not appear to be enclosed in a shell.

In general appearance this species resembles *S. javaensis* Micol. 1930 from the Java Sea. It differs in length, position of the excretory pore, α, β and γ values, and in the length of longest tooth; in view of the paucity of both collections it is deemed advisable to erect a new species at least until more material is available.

Symplocostoma longicolle Bastian

Fig. 11

Only one specimen, an immature female, was taken from among intertidal algae, Pennington Bay, Kangaroo Island.

L = 2·76 mm.; $\alpha = 30{\cdot}6$; $\beta = 3{\cdot}9$; $\gamma = 13{\cdot}1$; A–V = 54·7%

Width of body at head one-seventh of that at posterior end of oesophagus. Six relatively stout setae, length of each about half width of head; amphid oval, lying 5μ from anterior end, its breadth approximately a quarter that of head

width. Excretory pore one-ninth (five times depth of buccal capsule) and nerve ring a half length of oesophagus from head.

Buccal capsule 16μ long, diameter at anterior end 8μ, with five thickened rings with a circle of "rodlets" on its inner surface at level of second ring from mouth. Dorsal teeth about seven-tenths length of buccal capsule, its tip reaching between first and second rings. Pair of "lenticular" bodies just posterior to buccal capsule. No accessory teeth seen.

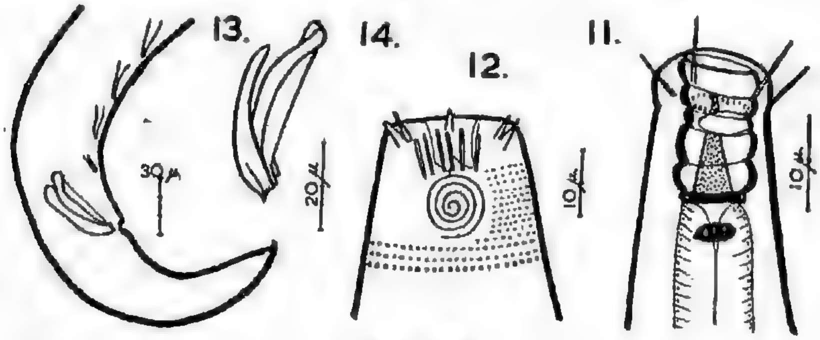

Fig. 11-14

Fig. 11, *Symplocostoma longicolle:* head. Fig. 12-14, *Harveyjohnstonia kartanum:* 12, head; 13, male tail; 14, spicules.

Ovaries reflexed, no ripe eggs. Length of tail about six times anal diameter.

This species agrees with *S. longicolle* in the characters of buccal capsule. The α, β and γ values vary somewhat from those given by Stekhoven (1935, p. 59) and 1950 (90), though α and β values agree with those of Allgen 1927, 217) for a juvenile specimen from Tasmania; the chief difference from the latter is in the position of the excretory pore, stated by Allgen to be 7·5μ from head, instead of 78μ as in our specimen. It is possible that there is an Australian and Tasmanian variety of *S. longicolle,* but in view of the immaturity of the specimens so far noted this is by no means certain.

Harveyjohnstonia n.g.

Cyatholaiminae—Cuticle without lateral differentiation, amphid spiral, buccal capsule with one small dorsal tooth, oesophagus without terminal bulb, ovaries reflexed, vulva in front of midbody, spicules alate, gubernaculum paired with spines distally, four tubular preanal organs, decreasing gradually in size from the anteriormost.

The genus is close to *Acanthonchus* and *Paracanthonchus.* It differs from both in the absence of lateral cuticular differentiation, and in the size of the buccal tooth; it differs from *Acanthonchus* also in the presence of spines on the gubernaculum (not mentioned by Cobb) and in the similarity of the preanal tubules; it further differs from *Paracanthonchus* in the length of the ribs of the buccal capsule.

Harveyjohnstonia kartanum n. sp.

Fig. 12-14

From littoral rock scrapings, Pennington Bay, Kangaroo Island.

♀: $L = 1{\cdot}45$; $\alpha = 20{\cdot}5$; $\beta = 7{\cdot}3$; $\gamma = 11{\cdot}1$; $A - V = 45{\cdot}1\%$

♂: $L = 1{\cdot}6$; $\alpha = 36$; $\beta = 8$; $\gamma = 14{\cdot}5$

Cuticle marked with transverse rows of punctations, in which no lateral differentiation occurs. Scattered setae present over body surface. Six short cephalic setae, their length one-sixth that of head width at this level, 22μ. Amphid spiral, of three and a half circles, its centre lying 15μ from anterior end of worm, its diameter about one-third that of head.

Buccal capsule 8-9μ in diameter, its base 8-9μ from anterior end of head, with about twelve ribs; tooth very small, at base of buccal capsule; diameter of head at this level 25μ.

Oesophagus without terminal bulb; nerve ring at ·1 mm. from head (at about half length of oesophagus), at which level body diameter is 38μ; at base of oesophagus body diameter is 50μ.

Ovaries reflexed, eggs not present.

Male tail two and half to three times anal breadth. Curved alate spicules 38μ long (about equal to anal breadth); gubernaculum paired, about three-quarters length of spicules, distal end somewhat enlarged, with several "thorns" and a posterior spine. Four tubular preanal organs, almost equidistant, anteriormost largest, others successively smaller. A few postanal setae present.

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THE AGE OF THE GAWLER RANGE PORPHYRY

BY R. K. JOHNS AND M. SOLOMON

Summary

Recent field work has disclosed that the Gawler Range porphyry, hitherto regarded as a pre-Sturtian extrusive, intrudes what are considered to be basal Cambrian sediments in the Corunna area on Upper Eyre Peninsula. The intrusions of porphyry and the unstressed granites of the Middleback Ranges area are thought to have taken place in the final stages of the orogeny following upon deposition of Cambrain sediments on terraces of the Adelaide miogeosyncline.

THE AGE OF THE GAWLER RANGE PORPHYRY [1]

By R. K. Johns and M. Solomon [2]

[Read 14 August 1952]

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SUMMARY

Recent field work has disclosed that the Gawler Range porphyry, hitherto regarded as a pre-Sturtian extrusive, intrudes what are considered to be basal Cambrian sediments in the Corunna area on Upper Eyre Peninsula. The intrusions of porphyry and the unstressed granites of the Middleback Ranges area are thought to have taken place in the final stages of the orogeny following upon deposition of Cambrian sediments on terraces of the Adelaide miogeosyncline.

INTRODUCTION AND PREVIOUS WORK

While engaged on a reconnaissance geological survey of the Iron Knob-Port Augusta district (Corunna Military Sheet) the authors found evidence to indicate that the Gawler Range porphyry is intrusive into sediments which are probably of Cambrian age.

Jack (1922) first reported pebbles of Gawler Range porphyry in the Corunna Range conglomerate. He believed the conglomerate represented a lower Cambrian overlap onto the Pre-Cambrian foreland of Eyre Peninsula. He believed the porphyry to be extrusive onto a Pre-Cambrian surface (1917). In 1947, Mawson also reported occasional porphyry pebbles in the conglomerates and concluded that the latter and the equivalent Tent Hill formation were younger than the porphyry. On lithological grounds he correlated these sediments with basal Adelaidean of the Emeroo Range (east of Port Augusta) and therefore dated the intrusion as pre-Adelaidean. Segnit (1939) suggested that both the Tent Hill formation and the Corunna conglomerate were equivalent to the Pound quartzite horizon which he placed in the Upper Pre-Cambrian. Ward (1949) also favoured an upper pre-Cambrian or basal Cambrian age for the conglomerate.

GENERAL GEOLOGY

The Gawler Range porphyry extends into the north-west corner of the Corunna military sheet and eastwards to the longitude of Myall Creek H.S. (see plan). The bordering sediments in this area are well-worked conglomerates, quartzites, sandstones and sandy shales. Highly-folded quartzites and shales are exposed over much of the area between the Corunna Range and Pandurra H.S. and these are overlain unconformably by conglomerates, sandstones, shales and flagstones outcropping in the Corunna Range and in the Roopena H.S.-Lincoln Gap area. They have been squeezed into a broad synclinal fold in the Corunna Range but at Lincoln Gap the beds are horizontal or show a gentle easterly dip. The age of these sediments is uncertain though it is believed that they represent the terrace or shelf facies of the lower Cambrian. The Corunna Range sediments are thought to be a coarse facies of the sandstone outcropping near Roopena H.S.

The underlying contorted quartzites and shales may be basal Adelaidean or equivalent to beds of the iron ore series in the Middleback Range, i.e., Middle Pre-Cambrian.

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[2] Department of Mines, Geological Survey of South Australia.

The general succession is summarized below:

	CORUNNA RANGE	LINCOLN GAP
Cambrian ?	Corunna sandstone, conglomerate and Quartzite	Lincoln Gap Flagstones Tregalana Shales Corunna sandstone

— Unconformity —

Adelaidean or
Middleback Group: Quartzites and Shales.

This sequence may be matched at Whyalla, Mt. Laura and in the Moonabie Range (Miles, Bulletin 33 of Geol. Surv. of South. Aust., unpublished).

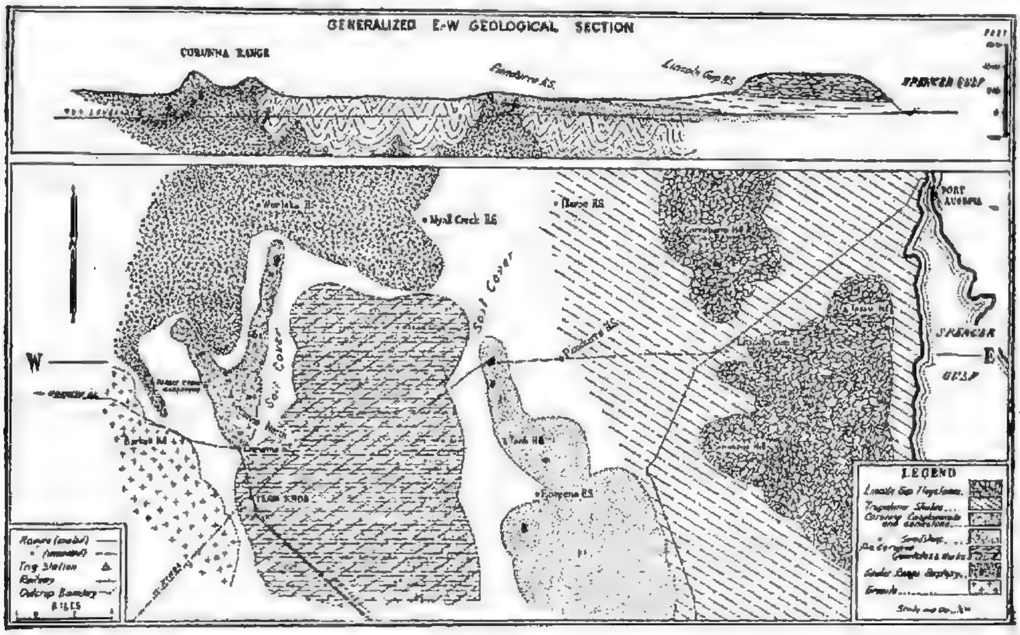

Fig. 1

THE AGE OF THE PORPHYRY

The following are the more important facts relating to the age of the Gawler Range porphyry and its mode of emplacement:

(1) A small body of Gawler Range porphyry intrudes the Corunna conglomerate three miles south of Wartaka H.S. The outcrop is of irregular shape and cross-cuts the bedding and at its margins shows chilling and partial digestion of the sediment.

(2) Two miles south-south-west of Roopena H.S. a plug of similar porphyry about 20 acres in area is flanked by Corunna sandstone. Near the contact with the igneous rock the sandstone is locally recrystallised and a dark hornfelsic facies is developed.

(3) The Corunna Range bifurcates north of the latitude of Tassie Creek, the two arms representing the limbs of a broad north-pitching synclinal fold, though the eastern limb is disturbed by faulting.

The low area between the ranges, the axis of the syncline, is now occupied by porphyry which, judging from the steepness of the limb of the fold and the relative elevations of the ranges and the valley between them, apparently intruded and digested the sediments in the axis of the syncline (see horizontal section).

Two other porphyry stocks were mapped in Corunna sandstone about four miles west of Pandurra H.S., but no contact phenomena were observed. The porphyry of these small bodies is generally of finer grain than in the main axis.

The evidence outlined above proves that the Gawler Range porphyry in this area is intrusive into the Corunna sediments. The form of the intrusion is indicated in the accompanying horizontal section.

Both Jack (1922) and Mawson (1947) reported the presence of porphyry pebbles in the Corunna conglomerate and concluded that the intrusion was older than the sediment. The authors, however, failed to find any such pebbles anywhere in the Range.

Howchin (Trans. Roy. Soc. S.A. 1928) recorded red and grey porphyry pebbles in the Sturt Tillite in the Crystal Brook area, and various geologists (Mawson, Sprigg, etc.) have suggested that they are similar to the Gawler Range porphyry. It is possible, however, that they were derived from the Wallaroo-Moonta or some other porphyry. Jack (1917) states that the Wallaroo-Moonta and the Gawler Range porphyries are similar in appearance.

RELATED IGNEOUS BODIES

Several other unstressed magmatic granites occur in the Middleback Range area, the largest of which is the Charleston granite. This outcrops near Moonabie at the southern end of the Range and is a pink, coarse-grained porphyritic variety. It intrudes a dense grey porphyry which is itself intrusive into the Adelaidean grit of the Moonabie Range succession. No pebbles of either grey porphyry or granite are to be found in the conglomerate which uncomformably overlies this grit. The conglomerate is thought to be equivalent to that in the Corunna Range.

Evidence therefore indicates that the granite post-dates the Corunna sedimentation.

A uniform-grained tor granite outcrops in the Burkett Hill area, west of Iron Knob, and appears to felspathise and isolate outcrops of Corunna conglomerate. The time relationship between the granite and the Gawler Range porphyry is not known.

The intrusion of these unstressed granites and the porphyry is thought to have taken place in the final stages of the orogeny which followed upon the deposition of the Cambrian sediments on terraces of the Adelaide miogeosyncline.

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TWO NEW CUMACEA FROM SOUTH AFRICA

BY HERBERT M. HALE

Summary

I am indebted to Dr. J. H. Day, Professor of Zoology at the University of Cape Town, for the opportunity of examining a small collection of Cumacea secured during the course of an ecological survey of the estuaries and shallow waters of the Union of South Africa. Cumacea were collected at four different localities and two species are represented; both are described herein as new.

TWO NEW CUMACEA FROM SOUTH AFRICA

By Herbert M. Hale *

[Read 14 August 1952]

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Fig. 1-4.

I am indebted to Dr. J. H. Day, Professor of Zoology at the University of Cape Town, for the opportunity of examining a small collection of Cumacea secured during the course of an ecological survey of the estuaries and shallow waters of the Union of South Africa.

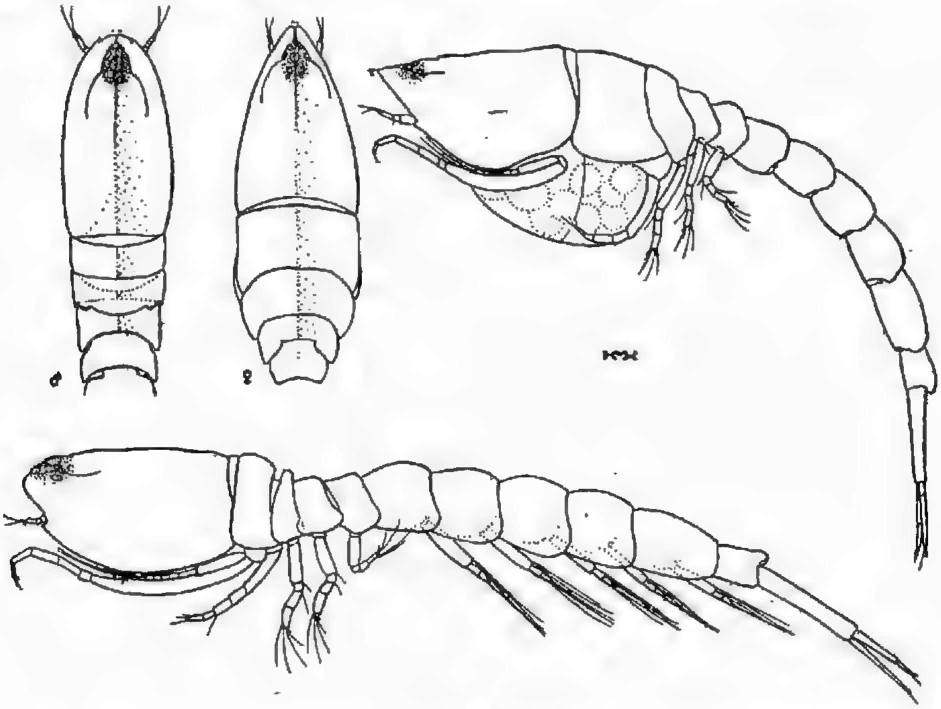

Fig 1

Iphinoe brevidactyla, type male and female from the side and cephalothorax from above (x 28).

Cumacea were collected at four different localities and two species are represented; both are described herein as new.

Genus Iphinoe Bate

Iphinoe brevidactyla sp. nov.

Ovigerous female—Carapace with a low median carina and with dorsal edge, as seen from the side, almost straight, slightly irregular but without serrations; it is one-fourth of the total length of animal, as wide as deep and seen from above is subtriangular in shape. Pseudorostrum about one-tenth of length of carapace, the lobes, as seen from above, very narrowly rounded apically and meeting towards their anterior ends. Antennal notch small, shallow and antennal tooth subacute. Ocular lobe wider than long, darkly pigmented and with lenses not distinct.

* Director, South Australian Museum.

The first of the five exposed pedigerous somites is short, the second long, about equal in length to the third and fourth somites together; the second to fourth somites have a low median dorsal carina.

Pleon a little shorter than cephalothorax and pedigerous somites together; telsonic somite slightly produced between bases of peduncles of uropods.

First antenna with third segment two-thirds as long as first, only about one-third as long again as second, and more than twice as long as the two-jointed flagellum.

Second maxillipeds with ischium, merus and carpus apically obliquely truncate; merus and carpus subequal in length and ischium almost half as long again as either.

Basis of third maxilliped (including outer lobe in length) more than half as long again as rest of limb; the outer lobe is rounded and subtruncate apically and reaches to level of middle of length of merus; the last-named is very little produced at anterior end and is distinctly longer than the carpus, which is broad, somewhat dilated apically, the anterior margin subtruncate and not forwardly produced; propodus broadly subtriangular in shape, about half as long as merus and little longer than the narrow dactylus.

First peraeopod with carpus reaching a little beyond level of antennal tooth; basis more than one-third as long again as remaining joints together; merus and carpus equal in length, propodus a little shorter than either and twice as long as dactylus.

Basis of second peraeopod barely longer than rest of limb; carpus distinctly longer than either merus or dactylus and twice as long as propodus; longest dactylar spine equal in length to dactylus.

Fossorial limbs with propodus and dactylus unusually short, together only about one-third as long as carpus, which is subequal in length to ischium and merus together; two of the subterminal carpal setae are as long as merus, carpus, propodus and dactylus together and reach to level of tip of the longest propodal seta.

Peduncle of uropod unarmed, half as long again as either of the rami, which are of equal length; exopod with four strong setae on inner margin of second segment and with two unequal terminal spines; first segment of endopod three-fourths as long again as second and with two subterminal inner spines of about equal length; second segment of endopod with two unequal terminal spines; remainder of inner edge of both endopodal segments margined with hyaline serrations.

Colour—Anterior half of carapace dark brown fading to yellowish posteriorly. Posterior half of second pedigerous somite and greater part of remaining somites suffused with brown. Basis of first peraeopods and posterior oostegites with dark brown markings.

Length 3·2 mm.

Adult Male—The carapace is more than one-fourth of the total length and as seen both from above and from the side is suboval in shape; as in the female the dorsal margin in lateral view is slightly irregular but without serrations. Pseudorostrum shorter than in female, somewhat downbent in front, the lobes meeting towards their rounded apices. Antennal notch wider than in female and ocular lobe larger with the lenses more distinct.

Second pedigerous somite not differing much in length from third to fifth somites.

Pleon longer than cephalothorax and pedigerous somites together; telsonic somite rounded posteriorly.

Second antenna with flagellum reaching to just beyond end of peduncle of uropod.

Third maxillipeds with basis more than twice as long as rest of limb; otherwise as in female.

First peraeopod as in female except that basis is more than half as long again as remaining joints together.

Basis of second peraeopod shorter than rest of limb; longest dactylar spine as long as propodus, and dactylus together. Fossorial limbs as in female.

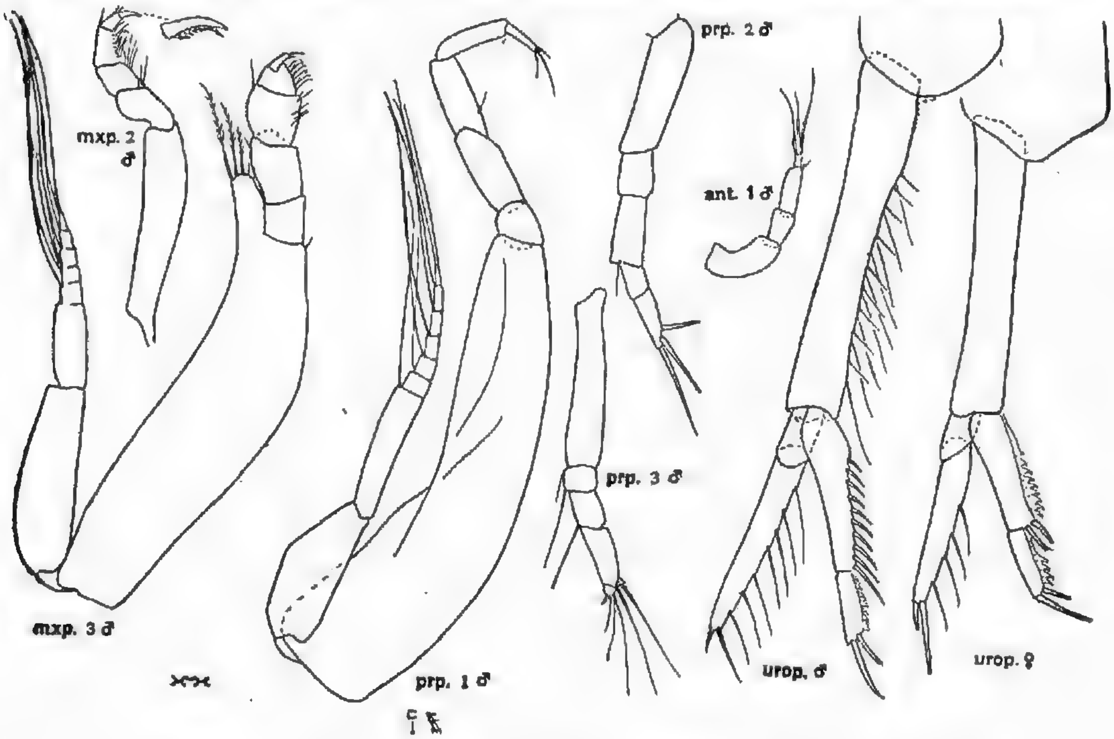

Fig. 2

Iphinoe brevidactyla, paratype male and ovigerous female; ant. 1, first antenna; mxp. 2-3, second and third maxillipeds; prp. 1, 2 and 3, first, second and third peraeopods; urop., uropods (all x 80).

Peduncle of uropod half as long again as either of rami and armed on inner edge (for posterior three-fourths of length) with two series of setae; exopod equal in length to endopod and with seven long setae on inner margin and two unequal terminal spines; endopod with first segment twice as long as second, its inner margin armed with ten spines, which successively increase in length, the posterior one being about equal in length to the longer of the unequal terminal spines of the second segment, which has inner hyaline serrations as in the female.

Colour—General colouration as in female, *viz.*, yellow ground colour largely suffused with dark brown.

Length 3·35 mm.

Locality—Union of South Africa: Langebaan Lagoon; from bottom in mid-channel and dredging in 3-8ft. water at high tide, on fine sand with patches of sandy mud (April 1949).

In *crassipes* Hansen and *pellucida* Hale the first segment of the endopod of the uropod is longer than the second, as in the species described above; both of them differ, however, in having the dactylus of the three posterior pairs of peraeopods relatively long and slender.

I. crassipes has been recorded from South Africa (Stebbing 1910, p. 412, pl. xlv). It differs further from *brevidactyla* in having the pseudorostrum upturned, while the third maxilliped has the merus greatly produced forwards and the carpus and propodus slender, not at all dilated.

The third maxilliped of the Australian *pellucida* (Hale 1944, p. 231, fig. 5-6) is also very different from that of *brevidactyla*, and the setae of the fossorial limbs are much shorter and stouter.

Iphinoe truncata sp. nov.

Ovigerous female—Carapace with a median longitudinal keel anteriorly, merging into a shallow groove with slightly raised edges in posterior half, and with upper margin, when viewed from the side, almost straight, a little

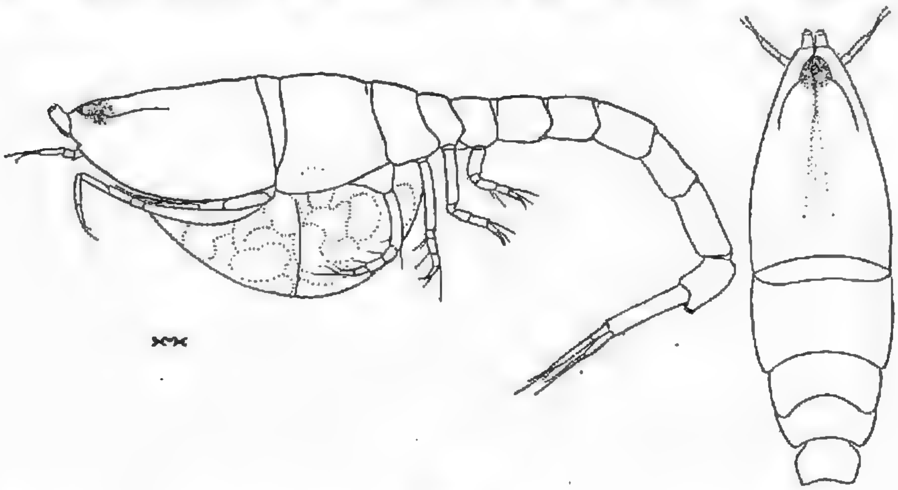

Fig. 3
Iphinoe truncata, type female; lateral view and cephalothorax from above (x 28).

irregular but without serrations; it is somewhat wider than deep, half as long again as broad and is one-fourth of total length of animal; seen from above it is subtriangular in shape, the sides gently curved and narrowly truncate anteriorly. Pseudorostrum short, the lobes truncate in front when seen from the side as well as in dorsal view, and meeting in front of the ocular lobe, which is as wide as long and darkly pigmented, the lenses indistinct. Antennal notch small, rather narrow, and tooth subacute (fig. 4, c. pace).

Second pedigerous somite half as long again as third, fourth or fifth somites, and first very short.

Pleon distinctly shorter than cephalothorax and pedigerous somites together; telsonic somite rounded posteriorly and a little produced between bases of peduncle of uropods.

First antenna with third segment about as long as first, three-fourths as long again as second, and two and one-half times as long as the two-jointed flagellum. Second antenna very small, two-segmentate (fig. 4, ant.).

Ischium of second maxilliped with anterior margin obliquely truncate; carpus barely longer than either ischium or merus and fully twice as long as propodus.

Basis of third maxilliped broad, its length (including outer lobe) half as long again as remaining joints together; the rounded outer lobe reaches to level of three-fourths of length of merus, which is widened to form an outer lobe, distally truncate and not at all produced forwards; carpus barely longer than merus, widened and truncate distally; propodus only about two-thirds as wide as and little shorter than carpus, and nearly twice as long as the slender dactylus.

Basis of first peraeopod stout, barely as long as rest of limb; carpus a little longer than propodus, about half as long again as either merus or dactylus and reaching to level of antennal tooth.

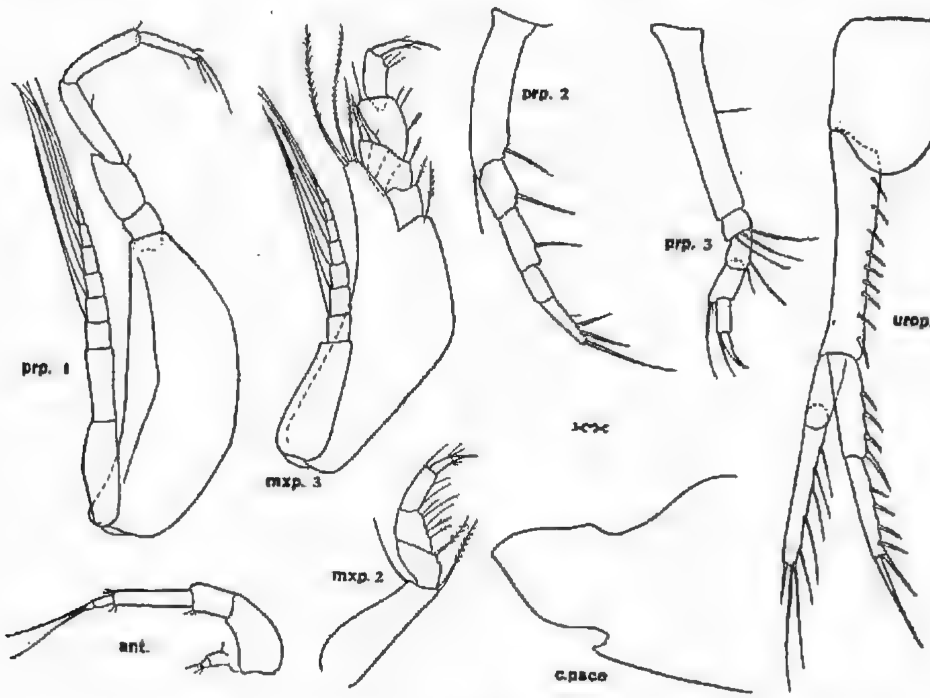

Fig. 4

Iphinoe truncata, paratype ovigerous female; ant., first and second antennae; mxp. 2-3, second and third maxillipeds; prp. 1, 2 and 3, first, second and third peraeopods; urop., telsonic somite and uropod; c. pace., pseudorostral lobe (all x 80).

Second peraeopod with basis shorter than remaining joints together; carpus little longer than either merus or dactylus and less than twice as long as propodus; longest dactylar spine equal in length to propodus and dactylus together.

Third to fifth peraeopods with merus, propodus and dactylus subequal in length and propodus only a little shorter; the longest carpal seta and the propodal seta reach to level of tip of dactylus; in the third peraeopods the basis is one-third as long again as rest of limb.

Peduncle of uropod barely longer than either of the rami (which are of equal length) and armed with nine or ten spines not differing much in size; exopod with five long setae on inner margin of second segment, which carries three terminal spines, the longest of which is distinctly more than half as long as exopod; endopod with first segment equal in length to second and

furnished on inner margin with four spines, the distal one subterminal and larger than the others, second segment of endopod with four spines on inner margin and with two unequal terminal spines, the longer equal in length to the segment.

Colour—Ground colour pale yellow, irregularly mottled with large dark brown chromatophores.

Length 3·56 mm.

Male—Only a single small example is available. In this the pseudorostrum is more downbent than in the female, the ocular lobe is larger and the first pedigerous somite is very small. The pleon is longer than the cephalothorax and pedigerous somites together. Peraeopods and uropods much as in female.

Length 2·0 mm.

Locality—Union of South Africa: The Haven, mouth of Nbanyana River; from top 2 inches of sand, clean with some detrius, no mud (Jan., 1950): St. Johns, Second Beach, from clean sand at mouth of estuary (type male, January, 1950); Umkomaas, at mouth of Umzimbazi River. from muddy sand and amongst stones (type ovigerous female January, 1950).

Ovigerous females vary in size; two of the examples taken with the type female are only 2·7 mm. in length and several from the other localities are under 3 mm. There is little variation in the armature of the uropods but the first joint of the endopod may be barely shorter than the second.

Most species of the genus differ from *truncata* in having the segments of the endopod of the uropod decidedly unequal in length. In those in which these segments are subequal the carapace has mid-dorsal serrations in at least the female.

References

HALE, HERBERT M. 1944 Trans. Roy. Soc. S. Aust., 68, (2), 225-285

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NOTES ON SOUTH AUSTRALIAN GRASSES

BY LINDLEY D. WILLIAMS

Summary

Nomenclature of South Australian grasses is revised in the light of recent study, using Ed. 2 of J. M. Black's "Flora of South Australia," Part I, as a basis. Four new species are briefly described and keys to the South Australian representatives of the genera Pennisetum, Bromus and Lolium are included.

NOTES ON SOUTH AUSTRALIAN GRASSES

By Lindley D. Williams

[Read 14 August 1952]

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SUMMARY

Nomenclature of South Australian grasses is revised in the light of recent study, using Ed. 2 of J. M. Black's "Flora of South Australia," Part I, as a basis. Four new species are briefly described and keys to the South Australian representatives of the genera *Pennisetum, Bromus* and *Lolium* are included.

Since the publication in 1943 of the second edition of Part I of the late J. M. Black's "Flora of South Australia" a number of important changes in the nomenclature of the grasses have appeared. This paper is an attempt to correlate all such alterations and additions. For completeness the additions and corrections in the second edition of Part II of Black's Flora are included.

Sorgum Moench is considered to be the correct rendering of the genus previously spelt *Sorghum* (R. Pilger in Nat. Pflanzenfamilien, Bd. 14 c (1940)).

Bothriochloa decipiens (Hack.) C. E. Hubb.—Synonym *B. ambigua* S. T. Blake (1944).

Hyparrhenia hirta (L.) Stapf in Prain, Fl. Trop. Afr. 9, 315 (1918). *Andropogon hirtus* L., Sp. Pl. 1,046 (1753).

An Old World perennial cultivated and escaping from demonstration plots at the Waite Agricultural Research Institute. It differs from our *Cymbopogon* spp., to which it is allied, in that the pairs of racemes are borne on relatively long flexuous peduncles and the base of the fertile spikelet is elongated into a sharp callus.

Paspalum vaginatum Swartz, in Prodr. Veg. Ind. Occ. 21, (1788).

Native of tropical sea coasts introduced and spreading in swamps and irrigation ditches near the mouth of the River Murray. It may be differentiated from the allied *P. distichum* L. as follows:—

A. Leaves to 3 mm. broad, folded in bud, whole plant glabrous except for a few long hairs on the ligule; spikelets 2 mm. long .... *P. vaginatum* Swartz (1)

AA. Leaves to 5 mm. broad, rolled in bud, hairy at base and at orifice of leaf-sheath; spikelets 3-4 mm. .... *P. distichum* L. (2)

Pennisetum ciliare (L.) Link (*Cenchrus ciliaris* L.) — J. M. Black, Fl. S. Aust. 2 (Ed. 2), 255 (1948).

Pennisetum clandestinum Hochst. ex Chiov. Annuar. Ist Bot. Roma 8, 41 (1903).

The latter, popularly known as Kikuyu Grass, is a creeping forage grass from Africa widely established in settled areas. The new species are incorporated in the following key:—

A. Spikelets 2-4, remaining more or less enclosed by the upper leaf-sheath; extensive rhizomes and stolons present *P. clandestinum* Hochst. ex Chiov. (1)

AA. Spikelets numerous in an exserted spike-like panicle, growing in dense tufts

B. Panicle 2-8 cm. long; inner bristles of the involucre plumose

C. Bristles 3 cm. long; spikelets 10-12 mm. in length *P. villosum* R. Br. (2)

CC. Bristles not exceeding 1 cm. in length; spikelets 4 mm. .... *P. ciliare* (L.) Link (3)

BB. Panicle exceeding 10 cm. in length; involucre of short scabrous bristles .... *P. macrourum* Trin. (4)

Phalaris tuberosa L. var. *stenoptera* (Hack.) Hitchc. in Wash. Acad. Sci. Jour. 24, 292 (1934). *P. stenoptera* Hack. in Repert. Sp. Nov. Fedde 5, 333, (1908).

This widely-cultivated forage plant has been regarded as typical of *P. tuberosa* L., but because of the absence of swellings at the base of the culms and the presence of short stout rhizomes the form occurring in this country is considered distinct and has been accorded varietal status. It was described from plants which appeared in the Toowoomba Botanical Gardens, Queensland, about 1902.

Amphipogon caricinus F. Muell. in Linnaea 25, 445 (1852); J. W. Vickery in Contrib. N.S.W. Nat. Herb. 1, (5), 281 (1950).

While *A. strictus* R. Br. var. *setifer* Benth. of the Mount Lofty Range is correctly named, the more widespread form previously known as *A. strictus* R. Br. should in fact be referred to the species enumerated above.

Phragmites communis Trin. instead of *Ph. vulgaris* (Lamk.) Crep. (J. M. Black Fl. S. Aust., 2 (Ed. 2), 255 (1948).

Koeleria michelii Cosson — Synonym *Avellinia michelii* Savi.

Distichlis distichophylla (Labill.) Fassett instead of *D. spicata* (L.) Greene, which is a distinct species — J. M. Black, Fl. S. Aust., 2 (Ed. 2), 255 (1948).

Add *Puccinellia distans* (L.) Parl. (J. M. Black, Fl. S. Aust., 2 (Ed. 2), 518 (1948). — For the sake of completeness Black's key is here reproduced:—

A. Panicle 6-12 cm. long, dense, narrow; spikelets about 10 mm. long, 6-12-flowered .... *P. stricta* (Hook. f.) Blom. (1)
AA. Panicle 8-20 cm. long, the slender branches soon spreading outwards; spikelets 4-5 mm. long, 3-6-flowered *P. distans* (L.) Parl. (2)

Festuca arundinacea Schreb. — Synonym *F. elatior* L. var. *arundinacea* Wimm.

The following names have been applied in recent Australian literature and are here recorded as synonyms only (Cross and Vickery in Contrib. N.S.W. Nat. Herb. 1, (5), 275 (1950; C. A. Gardn., Fl. W. Aust. 1, (Pt. i), 96 (1952).

Bromus arenarius Labill. — *Serrafalcus arenarius* (Labill.) C. A. Gardn., Fl. W. Aust. 1, (Pt. i), 96 (1952).

Bromus mollis L. — *Serrafalcus mollis* (L.) Parl. Pl. Rar. Sic. 2, 11 (1840).

Bromus hordeaceus L. — *Serrafalcus hordeaceus* (L.) Green et Godr. Fl. Fr. 3, 590.

Bromus macrostachys Desf. — *Serrafalcus macrostachys* (Desf.) Parl. Fl. Ital. 1, 96 (1798).

Bromus catharticus Vahl — *Ceratochloa cathartica* (Vahl) Hert. Rev. Sudamen. Bot. 6, 144 (1940).

The following diagnosis of the genus *Bromus* represented in the State of South Australia has proved useful: —

A. Lemmas with a sharp keel, 1st glume 7-nerved, 2nd 9-nerved, awn very short .... *Bromus catharticus* Vahl (1)
AA. Lemmas not sharply keeled.
B. 1st glume 1-nerved, 2nd 3-nerved.
C. Awn twice the length of the fl. gl., stem, leaves and leaf-sheaths downy, panicle, loose .... *B. rigidus* Roth. (2)
CC. Awn a little longer than length of fl. gl.
D. Stem glabrous, lamina long-haired above, glabrous or pubescent below and on sheath; panicle loose at least prior to maturity, awns not diverging ... *B. madritensis* L. (3)
DD. Stem pubescent, leaves and leaf-sheath downy; panicle dense, awns spreading at maturity .... *B. rubens* L. (4)
BB. 1st glume 3-nerved; 2nd 5-7 nerved, flowers divergent after flowering .... *B. arenarius* Labill. (5)

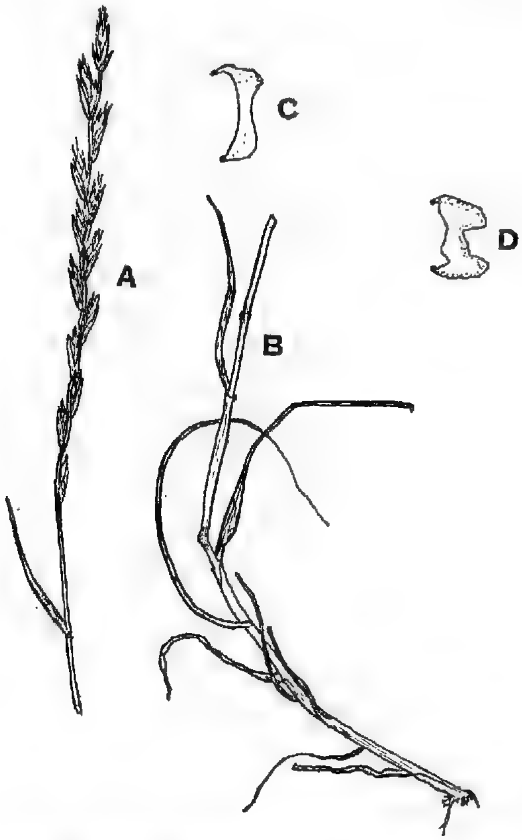
BBB. 1st glume 5-nerved, 2nd 7-nerved, flowers contracted at summit not diverging.

E. Spikelets thick, awns straight.

F. Spikelets softly pubescent .... *B. mollis* L. (6)

FF. Spikelets glabrous .... *B. hordeaceus* L. (7)

EE. Spikelets flat, awns finally bent and spreading horizontally .... *B. macrostachys* Desf.



A, flower spike. B, lower portion of plant; C, cross section of rachis of *Lolium rigidum;* D, cross section of rachis of *Lolium perenne.*

Eleusine tristachya (Lam.) Lam. Tabl. Encyl., **1**, 203 (1791).

Specimens of the grass referred to *Eleusine coracana* (L.) Gaertn. (J. M. Black, Fl. S. Aust. 2, (Ed. 2), 518 (1948)) were sent to Miss J. W. Vickery of the New South Wales National Herbarium who writes, "The grass specimen you enclosed is *Eleusine tristachya,* as I suspect is all the other material which has been recorded in Victoria and South Australia as *E. coracana.* The latter is a much heavier-headed plant with protruding large grains, which has been used as 'millets' by the natives of some countries." *E. tristachya* (Lam.) Lam. is a native of South Africa introduced into both American continents, Asia and Australasia.

Lolium loliaceum (Bory et Chaub.) Hand. - Mazz. in Ann. Nat. Hofmus., Wien, **28**, 32 (1914); *L. subulatum* Vis. Fl. Dalm., **1**, 90 (1842).

Lolium rigidum Gaud. Agrost. Helv. 1, 334 (1811).

T. J. Jenkin and P. T. Thomas, in J. Genet., 37, (2), 255 (1939), working with material grown from Australian seed, described two distinct species which were subsequently identified by C. E. Hubbard as *Lolium loliaceum* (Bory et Chaub.) Hand.-Mazz. and *L. rigidum* Gaud. *L. rigidum* is a native of the Mediterranean region and is the principal constituent of "Wimmera Ryegrass" cultivated and widely naturalised. Plants which tally with Jenkin's description and illustrations of *L. loliaceum* have been collected on roadsides and in pasture in settled areas. Before attempting to identify specimens it must be recognised that hybrids between the species frequently occur—there are in fact hybrids between *L. multiflorum* and *L. perenne* commercially produced in New Zealand, and one strain is widely grown here under the name of "H1 Ryegrass." The following is an attempt to clarify the position:—

A. Flowers oblong swollen in fruit, outer glume exceeding the spikelets .... *L. temulentum* L. (1)

AA. Flowers lanceolate, not swollen in fruit.

B. All fl. gls., except the lowest, with an awn as long, rhachis narrowly grooved immediately below insertion of the glumes .... *L. multiflorum* Lam. (2)

BB. Fl. gl. awnless or with awns which tend to be longer towards the tips of the spikelets and usually much shorter than the lemma.

C. Outer glume as long or longer than the spikelets; rhachis of spike broader than side to which the spikelets are attached, in mature specimens angles of rhachis smooth .... *L. loliaceum* (Bory et Chaub.) Hand-Mazz. (3)

CC. Outer glume shorter than the spikelets; side to which the spikelets are attached broader than the face of the rhachis.

D. Leafy perennial tuft; nodes green; rhachis narrowly grooved; spikelets awnless .... *L. perenne* L. (4)

DD. Stemmy annual; nodes dark reddish-brown; groove below insertion of glumes broad and shallow or absent, angles of the rhachis scabrid ... *L. rigidum* Gaud. (5)

Monerma cylindrica (Willd.) Coss & Dur. Expl. Sci. Alger. 2, 214 (1859); *Lepturus cylindricus* (Willd.), Trin. Fund. Agrost., 123 (1820).

Parapholis incurva (L.) C. E. Hubb, Blumea Sup. 3, 14 (1946); *Pholiurus incurvus* (L.) Schinz and Thellung, Vierteljahrs. Nat. Gesell., Zurich 66, 265 (1921).

Pholiurus pannonicus (Host.) Trin. remains the type of the monotypic genus *Pholiurus* Trin. which is characterised by its non-articulate rhachis.

Psilurus incurvus (Gouan) Schinz and Thellung Vierteljahrs. Nat. Gesell., Zurich 58, 40 (1913); *P. aristatus* (L.) Duval-Jouve in Bull. Soc. Bot. Fr. 13, 132 (1866).

Hordeum leporinum Link. in Linnaea 9, 133 (1835).

The above instead of *H. murinum* L. which is a different species of North and Middle European origin not known to occur in this country. *H. leporinum* Link. is an introduced weed from the Mediterranean region.

New South Wales botanists have referred the plant formerly known there as *Hordeum marinum* Huds. to another species., *viz., H. hystrix* Roth. I find, however, that in the case of South Australian specimens the original determination is the correct one. Miss Vickery, however, assures me that our species is

conspecific with material she has referred to *H. hystrix*. Mrs. Agnes Chase, Research Associate, United States National Museum, who has revised Hitchcock's "Manual of the Grasses of the United States," has, in addition to supplying fragments from herbarium specimens, kindly listed the main differences between the species in question.

A. Glumes of lateral spikelets dissimilar, one broad and flat in the middle; floret of lateral spikelet awned .... *H. marinum* Huds. (1)

AA. Glumes of lateral spikelets similar, one only slightly thicker; floret of lateral spikelets only awn-tipped or awnless .... *H. hystrix* Roth. (2)

I am especially indebted to Miss C. M. Eardley, Systematic Botanist, Botany School, University of Adelaide, for encouragement and helpful criticism.

ON SOME SOUTH AUSTRALIAN COSSIDAE INCLUDING THE MOTH OF THE WITJUTI (WITCHETY) GRUB

BY NORMAN B. TINDALE

Summary

The hitherto unknown female of Xyleutes leucomochla Turner 1915 is described, also its life-history on the roots of one of the witjuti (witchety) bushes (Acacia ligulata). Larvae have become known as aboriginal articles of food but had never been reared to maturity.

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By NORMAN B. TINDALE *

[Read 11 September 1952]

595.787 (94)

SUMMARY

The hitherto unknown female of *Xyleutes leucomochla* Turner 1915 is described, also its life-history on the roots of one of the witjuti (witchety) bushes (*Acacia ligulata*). Larvae have become known as aboriginal articles of food but had never been reared to maturity.

Brachypterous females of a new species, *Xyleutes biarpiti*, are described; also its life-history on the roots of *Zygophyllum fruticulosum*.

The previously undescribed brachypterous females of two other Cossids, *Xyleutes amphiplecta* Turner, and *Catoxophylla cyanauges* Turner are recorded with some life-history details.

The value of these insects as foods for aborigines is noted and the conclusion stated that they provide an almost essential element in their diet.

INTRODUCTION

Between June and September, the time when most field workers visit the Western Desert, only immature stages of various Cossid larvae are present. Hence several species which feed on the roots of shrubs and annuals, and which are used as food by the aborigines, are known as larvae, but have not been bred to maturity and identified with the moth.

In April 1951 a fortunate and, for this writer, a rare opportunity to visit Ooldea, on the Trans-Australian Railway line, came earlier than usual in the season. This enabled him, with the aid of aboriginal children, to find adult larvae and pupae of two species, and to rear them to maturity. He was able to confirm that at least three species of Cossids in arid Australia have brachypterous females, incapable of flight.

XYLEUTES LEUCOMOCHLA Turner 1915

Female—Head dark brown with a tuft of white scales at base of antennae; palpi black, short, terminal segments moderate, ovoid and smooth-scaled; antennae relatively long, tapering to a fine point, minutely bepectinate; thorax brown with some white scales; an inverted black V-mark on thorax, tufts on tegulae white, abdomen brown with some white scales more evident laterally; thorax below brown, legs brown, base of abdomen white. Forewings with costa slightly sinuate, apex not well rounded, termen rather straight, obtuse-angled at inner margin, brown with a base of obscurely delimited white reticulate markings, outlined with blackish-brown scales from apex to lower margin of cell; a larger white area near apex of cell partly margined with black; towards inner margin white scales are scattered among the brown ones. Hindwings with costal third white, rest of wing pale brown with traces of reticulate markings near termen. Wing length 60 mm.; expanse 135 mm.

Locality—South Australia, Ooldea Soak, 27 April 1951, N. B. Tindale (allotype female, I. 19094, in South Australian Museum); Woomera, 12 March 1950, another female, found by a survey party.

* South Australian Museum.

The second female specimen is much larger. It is rather worn but, even with the tips of the forewing wanting, exceeds 170 mm. in expanse. The inner margin of the forewing is somewhat more concave than in the figured specimen.

These two females appear unquestionably to be the other sex of *Xyleutes leucomochla* Turner, which was previously known only from male examples

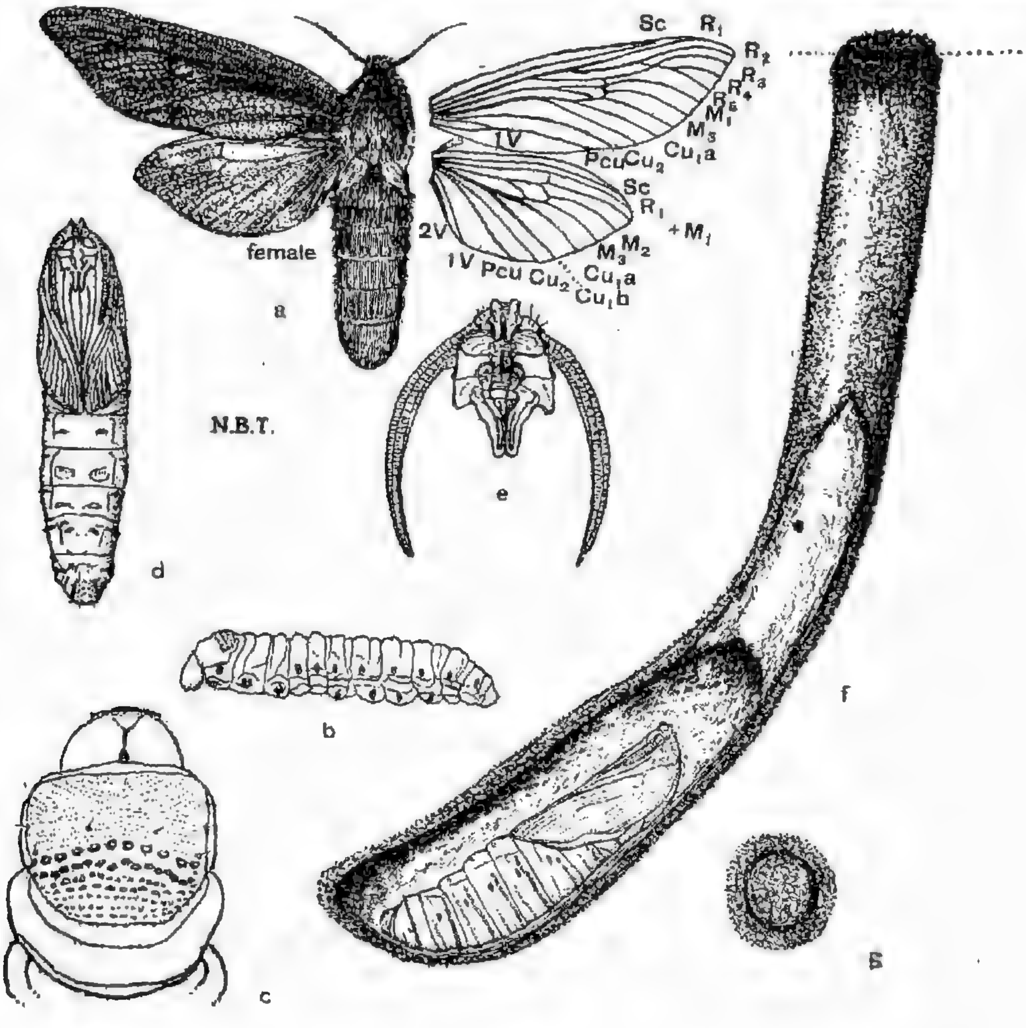

Fig. 1

Xyleutes leuchomochla Turner. a,allotype female, Ooldea Soak, South Australia; b, larva; c, head and thorax of larva; d, pupa of allotype female; e, pupal mask; f, pupa in silken pupal tunnel; g, unopened lid of tunnel from above.

taken at Nhill in Victoria, and at Cunderdin and Lake Darlot in Western Australia, and of which the life-history was unknown.

It is to be noted that Turner's type of *X. leucomochla,* so labelled by him, is from Cunderdin, Western Australia, and is in the South Australian Museum collection, No. I. 14331, and not in the National Museum Melbourne, as stated seemingly in error, in the original description; it was a specimen taken by the late Mr. R. Illidge. There is another male in the South Australian Museum collection from Murray Bridge, South Australia.

Males are more noticeably brown in colour than the described females but the markings are similar.

Occurrence—Many empty pupal shells were found among leaf debris. They were standing up from silk-lined vertical tunnels placed within a foot or so of the butts of tall *Acacia ligulata* shrubs. Native boys indicated that most of the moths already had emerged. After digging near the butts they secured numbers of larvae, ranging from 42-80 mm. in length, and one pupa almost ready to emerge. The pupal chamber in which it was found is a curved cylinder of silk in the sand, its lower extremity placed close against the butt of the shrub. The chamber is closed at the bottom and 230 mm. in length (fig. 1 f). The lower 100 mm. is wider (25 mm.) than the 18 mm. diameter of the upper part which at the top appears as if it has been coated with a sealing substance, darker than the normal silk of the tunnel. It has a sealing cap of silk coated in a similar manner. In the pupal tunnels of emerged moths this cap has been neatly cut around and thrust to one side. The silk lining the tunnel is smooth and grey in colour.

The larvae feed externally on the roots of *Acacia ligulata* shrubs, remaining in a silken chamber against the root. This chamber afterwards is remodelled to serve as the pupal shelter; the part of the root being eaten is incorporated into the walls of the chamber. The bulk of wood eaten is relatively small and it would seem that, to an extent, the larva relies on the flow of sap for food, the jaws principally being used to keep the wounds in the root active and fresh.

A larva placed in a glass-topped box with an apple and sand quickly formed a chamber and settled down for some weeks in its strange environment, so that some of its habits could be observed. Unfortunately it succumbed without pupating after having been disturbed when renewing the food. It had eaten the apple until this had begun to decay.

The Cossids emerge in the early autumn. It seems probable that the insect passes at least two years in the larval state. Partly-grown larvae of around 40 mm., as well as a full-grown larva, of 80 mm., a ready-to-emerge pupa, and newly-vacated pupal shells were taken at the one season.

The pupa found while the boys were digging emerged in the late evening of the same day, just before 9 p.m., and despite the mishandling it may have received while being unearthed, made a tolerable specimen.

Larva—An apparently adult larva was 80 mm. in length, cylindrical, and 15 mm. in diameter; another, measured after preservation in alcohol, was 57 mm. in length in the contracted position and weighed 6·5 grams; two half-grown larvae measured 46 and 42 mm. (39 and 36 mm. in alcohol), diameter 12 mm. They weighed 3·0 and 2·6 grams. Larvae are creamy-white in colour with the head, prothorax, the spiracles and the appendages some shade of chestnut brown. The brown is usually paler on the posterior half of the prothorax. The form (fig. 1, b and c) is that generally characteristic of the family, and the larvae are naked, save for the inconspicuous primitive hairs. The ultimate segment of the abdomen bears two short, up-turned spines, one on each side of the midline, which appear to serve as anchor when the larva is thrusting itself forward in its burrow.

Pupa—That of a female was 74 mm. in length, 16 mm. in diameter, smooth, chestnut brown with darker brown chitinized extremities (fig. 1, d, e and f). The form of the facial mask is shown in the figure.

The oft-used Austral-English term *witjuti* or *witchety* applied to the grubs originally was taken from the Arabana native language by the late Sir Edward Stirling and put into print, with the spelling *witchety*, in a paper before the Royal Society of South Australia (Transactions 14, 189, 159). The occasion was the description of attempts made by a Mr. Benham, at Idracowra, to feed

"witchety grubs" to the then newly discovered marsupial mole *(Notoryctes typhlops)*. Lydekker (Marsupialia, 1894, 191) misquoted the word as "witchetty" and this spelling was followed by Spencer and Gillen and others writing about the aborigines. The true name and Geographic II spelling of the Arabana term is *mako witjuti,* pronounced with stress on the initial syllables. *Witjuti* refers to the shrub, not to the grub, and must be prefixed by the word *mako,* meaning grub.

Most of the aborigines present at Ooldea during the time of the present writer's visit were Ngalea people from North-west of Ooldea, together with some displaced Jangkundjara tribes-people who had migrated from the Everard Ranges after the great drought of 1914. Their name for the larvae of the present species was *mako wardaruka,* meaning grubs of the *wardaruka* (*Acacia ligulata*) shrubs. The pupae they term *mako miring wardaruka,* or simply *mako miring,* while the adults are *kinta-kinta wardaruka* or moths of the *wardaruka.* They are stated to appear only at the beginning of the cold season. The empty pupal shells are said to be *ilungu* or "dead."

The time of the year when pupae rise to the surface in their burrows is important to the aborigines, since numbers can often be gathered, just before they emerge, without the labour of digging deeply for them. Particularly at the end of summer the *Pitjandjara* sing a song about this anticipated event, *"Wardaruka miring tjarei"* "Acacia trees pupae are carrying." The song is one popular at evening dances in which women and children are present and take part. The Pintubi people at the northern edge of the Western Desert call the same or similar pupae *wanman-mbiri* or *wanman-mbiring.* The Ngalia (not Ngalea) people of Yuendumu, Central Australia, sing a similar song about *wanman-mbiring.* Among the Pitjandjara, Pintubi and other tribes of the central part of the Western Desert the grubs from *Acacia ligulata* and the similar ones, called *mako ilkoara* by the Pitjandjara, from *Acacia kempeana* (not yet reared or identified) furnish a not inconsiderable daily part of their diet. Women and children spend much time digging for them and a healthy baby seems often to have one dangling from its mouth in much the same way that one of our children would be satisfied with a baby comforter.

The larvae may be eaten raw, and are cooked by gently rolling in warm ashes raked from a fire. When cooked they taste like pork rind, when raw they are like scalded cream, or butter. It is probable that, for natives, they provide that portion of a healthy diet which civilised man obtains from butter. Aborigines with access to *witjuti* grubs usually are healthy and properly nourished. At Ooldea the larvae were still present in such abundance that it was possible, in less than an hour, for half-a-dozen aboriginal boys to gather an estimated half-pound weight of larvae of two species, all within a few hundred yards of a soakage well where up to 400 aborigines are artificially concentrated near a Mission Station. [The Mission is being disbanded in favour of one further south near the coast.] Before the days of the Station the area had been, probably for many centuries, a stand-by water for aborigines, yet the *Acacia* shrubs and the larvae have still thrived, an indication of their regenerative capacity and permanent value as a food source. The present author, when in the Mann and Musgrave Ranges in 1933, while observing nomadic Pitjandjara aborigines, in company with Dr. C. J. Hackett, over a period of several months, noted that part of nearly every day's diet consisted of these larvae. Even grown men did not neglect to dig up and eat some, and afterwards might carry one or more pinched under their headband or in their belt, as tit-bits, either for themselves or for their children. Plate v, fig. 1, shows aboriginal children digging out such Cossid grubs from the roots of *Acacia kempeana* in the Musgrave Ranges. They also find Buprestid beetle larvae. Plate v, fig. 2, shows a Pitjandjara young man who, noticing

some evidence of the presence of a grub, is digging in sandy ground near Arukalanda in the Western Musgrave Range. On such sandy flats *Salsola kali* often has Cossid grubs in its roots.

The weaning of aboriginal children is an often violently noisy and tearful process when, as happens, it has been delayed until the infant is three or more years of age; the children are pacified by being given grubs to suck and to eat; often they may be seen with one dangling from the mouth while they play. It may not be too much to assume that the aborigines' ability to rear healthy children in the harsh environment of the Western Desert is based to no inconsiderable degree on the wide presence and availability of these larvae. Their time of great hardship comes when droughts and the absence of summer monsoonal rains hampers the emergence of the moths and the establishment locally of new generations of larvae.

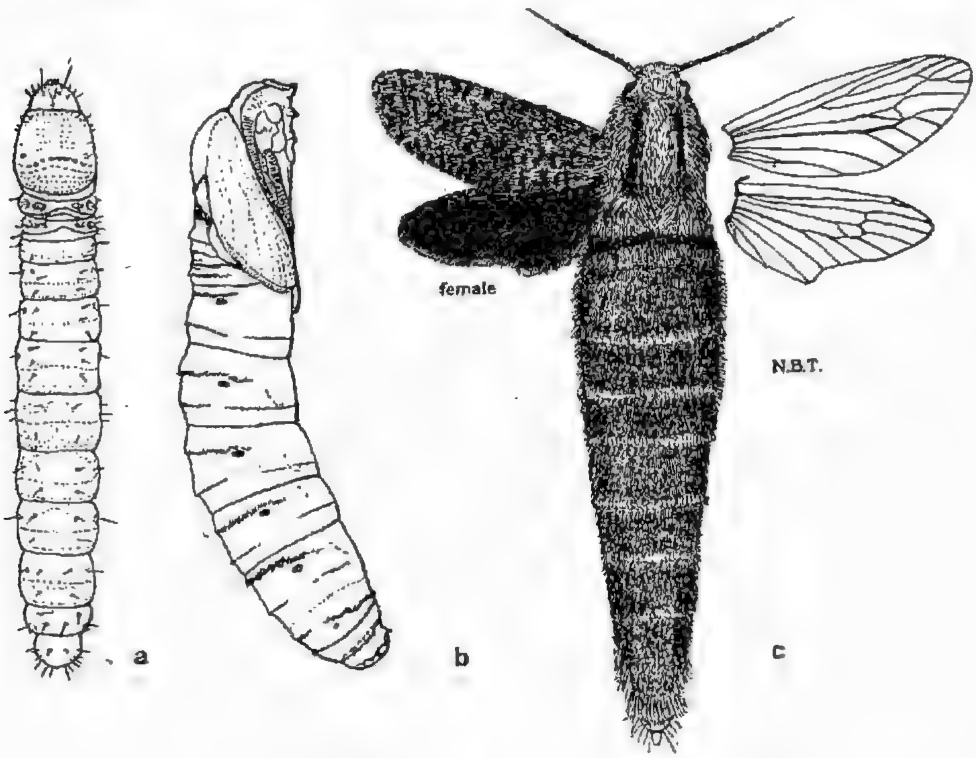

Fig. 2
Xyleutes biarpiti Tindale. Ooldea Soak, South Australia. a, larva; b, pupa; c, holotype female.

It seems probable, from statements of natives and the observed presence of part-grown larvae in the roots at the same time as adult larvae and pupae, that the life cycle is spread over more than one season.

Xyleutes biarpiti sp. nov.

Female—Head uniformly dull ochreous; palpi short, only terminal segment projecting from face; antennae short tapering simple, about one-half length of wing; thorax with patagia and tegulae ochreous, an inverted U-shaped black mark; abdomen brown with mixed black and ochreous scales, posterior margin of each segment with longer ochreous rough hairy scales. Forewings very short,

with costa convex, apex evenly rounded, termen rounded, ochreous with a reticulate pattern of black spots; hindwings short, apex rounded, slightly concave at inner angle, brownish-black with ochreous fringes. Wing length 14 mm.; expanse 33 mm.; total body length 36 mm.

Locality—South Australia: Ooldea Soak, 27 April 1951, N. B. Tindale (Holotype a female, I. 19095, and paratype females in South Australian Museum); Western Australia; Balladonia, a paratype female, taken by Mrs. Crocker.

The Balladonia example is slightly brighter in colour than Ooldea ones and shows a patch of reticulate dark-orange pattern on the termen of hindwing as well as on the costa; there is more orange scaling on the distal half of each abdominal segment.

The females are entirely incapable of flight and progress by crawling rapidly along the ground while vibrating their wings. Unfortunately only this sex is available for study, since an alert native mouse pounced on and successfully escaped with the only reared male while it was still resting and drying its wings. Only a casual examination of it had been made. It was very small, fully winged, with the antennae broadly pectinate in the basal half.

This species seems not to be very close to any other described form. Females differ from the equally small-winged females of *X. amphiplecta* Turner in the dull ochreous to bright orange-yellow ground colour against the slate-grey of that species. The rather regular reticulate black pattern of the forewings is similar in both forms. The larvae show differences in habit, those of *X. biarpiti* being borers in the roots of *Zygophyllum* whereas those of *X. amphiplecta* are relatively free-living earth or root-crown dwellers which are capable of shifting from one food plant to another.

The foodplant is *Zygophyllum fruticulosum* A-P de Candolle. According to Prof. J. B. Cleland, to whom I am indebted for the identification, the plant at Ooldea almost certainly is the variety *eremaeum* Diels. It is a four-petalled yellow- (sometimes white-) flowered perennial shrub with slender, rigid stems and linear leaflets.

Native children, by digging with short sticks at the bases of the shrubs, found plentiful supplies of the larvae and discovered also a few pupae. Seemingly they are able to detect the presence of larvae by subtle differences in the state of growth of the plants as compared with shrubs free of infestation. In some areas nearly every second shrub had a grub or grubs boring in its roots. The bulk of food yielded by each larva is small, no more than 2·2 grams for a full-grown female larva, but children spend much time gathering them. The larvae from the roots of the *Zygophyllum* bushes or *biarpiti* are called by them *mako biarpiti, i.e., mako* or grubs of the *biarpiti*. The pupae are *miring biarpiti* or simply *miring*.

The larvae and pupae are in chambers within the main root-stock of the shrubs; the pupa has an escape tunnel sealed with silk extending towards the surface of the sand. One female was just emerging at about 4 p.m. when dug out on 27 April. It proved to be brachypterous, as were the other subsequently reared female examples. These also emerged at about dusk.

Life Stages—The egg has not been examined. The larva is of normal Cossid form (fig. 2a), rather slender, with the ridged spines on the thorax rather slight. The head and thorax are of the palest chestnut-brown with the mouth parts and the thoracic processes dark chestnut; the body is white, smooth, and save for the inconspicuous primitive setae is naked; length of an apparently full-grown larva 51 mm.

Pupa (fig. 2b) pale chestnut-brown with head parts, thorax, wing cases, and posterior margin of each abdominal segment darker, the last-named giving a

generally banded appearance to the pupa; the series of body spines are finely and irregularly serrate, two rows to each body segment, with the anterior row more prominent than the posterior one; there is an almost complete ring of spines at the apex of abdomen with ventral traces of a second circle of them. Length of pupa of a female 43 mm., of a male 23 mm.

XYLEUTES AMPHIPLECTA Turner

Male—Head grey, palpi not projecting beyond frons; antennae strongly bipectinate to two-thirds, then filamentous. Thorax grey with an inverted U-shaped black mark inwardly edged with white; abdomen dark grey with white on the posterior margins of the segments. Forewings light grey with black markings; ground colour generally lighter in outer third, near termen, and near inner margin. Hindwings grey with dark brown reticulate markings, generally paler near termen. Forewing length 21 mm.; expanse 49 mm.

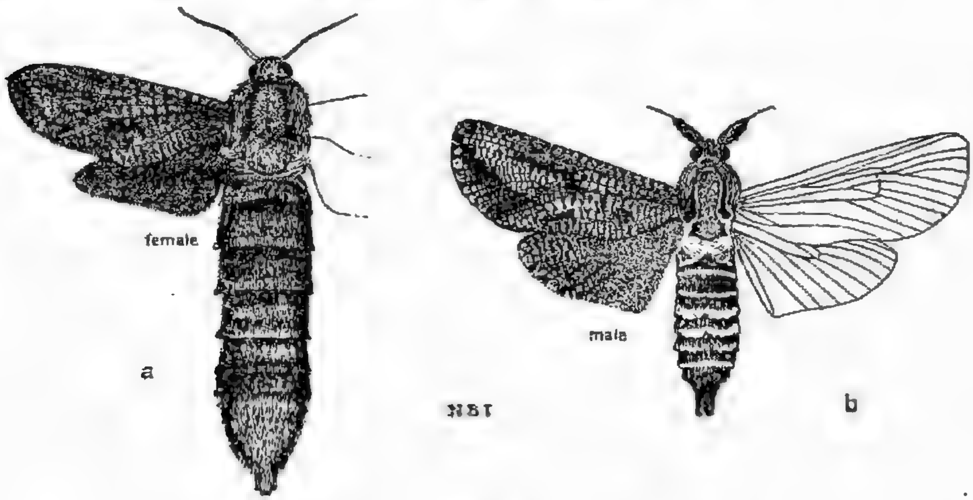

Fig. 3

Xyleutes amphiplecta Turner. Renmark, South Australia, L. O. Humphries.
a, allotype female; b, male.

Female—Head and thorax grey with an inverted U-shaped black mark; thorax from some angles displaying a purplish-blue sheen; abdomen grey with obscure darker transverse bandings. Brachypterous; forewings greyish-fawn with numerous transverse black strigulae; hindwings darker, with strigulae obscurely indicated in distal half. Forewing length 22 mm.; expanse 51 mm.

Locality—South Australia: Renmark (November to February), Mr. L. O. Humphries (allotype female, December 1945, I. 19096 in South Australian Museum); Loxton (March), Mr. and Mrs. R. George.

Presence of a purplish-blue sheen on the thorax is reminiscent of that seen in *Catoxophylla cyanauges.*

The elucidation of the life-history of this interesting species with its brachypterous female has been due to the interest of Mr. L. O. Humphries, who has passed to us a long series of specimens taken between 1941 and 1952.

The male which was very briefly described in these Transactions (1932, p. 195) has been taken at Dalby, Milmerran, Injune, Charleville, Goondiwindi, Talwood and Cunnamulla in Queensland; Brewarrina in New South Wales, and Birchip in Victoria. There are five paratypes in the South Australian Museum. It is far smaller in bulk that the female and very active on the wing.

According to an identification made by the late Dr. A. Jefferis Turner, the larvae in Queensland feed on *Bassia*. However, in South Australia the food plant is *Pachycornia triandra* (samphire).

Fishermen along the Murray River use the larvae as bait. They scrape the earth just below the level of the ground with a spade. Nearly vertical holes suggest the presence of larvae; unbroached lids to the shelters confirm this. Aborigines scrape the ground with digging scoops and smell the holes, thus detecting the high humidity maintained in occupied burrows; a conveniently hooked stick retrieves the grub.

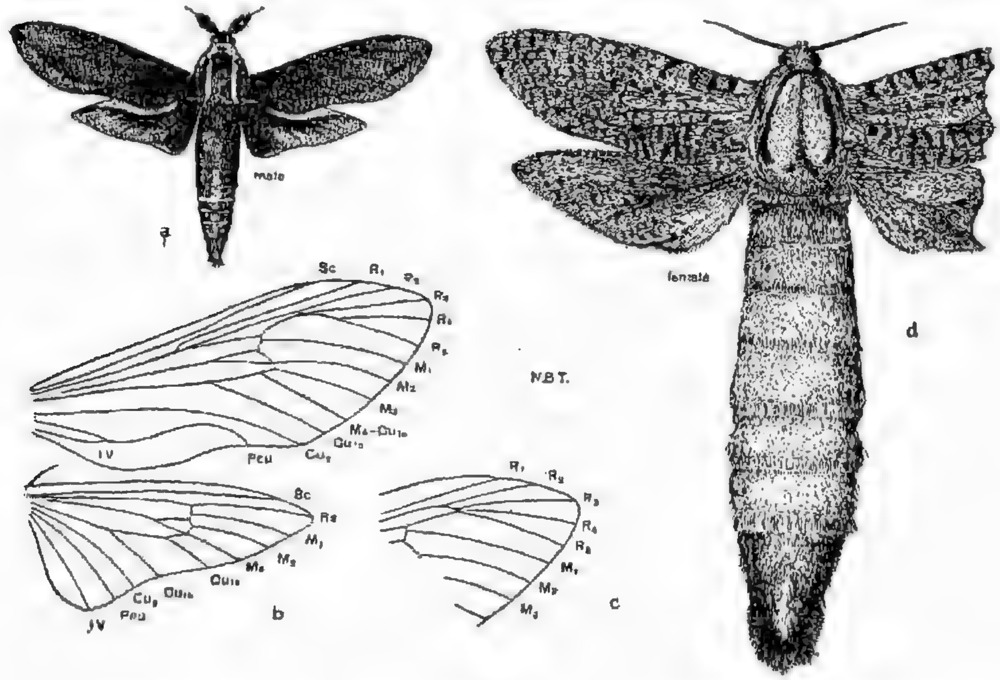

Fig. 4
Catoxophylla cyanauges Turner. Central Australia, Capt. S. A. White. a, male; b, male venation; c, variation in male venation; d, allotype female drawn to larger scale than male.

Unlike many others of the family the larvae are relatively free-living in that they can migrate from one shrub to another. They are usually to be found in or near the crown of the foodplant. Between late November and February the larvae are of large enough size for use as bait and are then taken in numbers.

The completely flightless females crawl actively over the ground, often with their wings folded against the body. They emerge in late summer when the air is humid or there is rain.

Mr. Humphries tells me that when digging for bait near *Pachycornia* roots at Renmark in late 1941 he found a female pupa ready to emerge. Having been disturbed it did so while he continued digging. Almost as soon as it had freed itself from the pupal case several males appeared fluttering about it, although it was broad daylight.

On this or another occasion he rested a newly emerged female on his coat lapel while taking it home; several males appeared and made futile advances to his coat which he had left outside his house when he took the moth inside. There were no *Pachycornia* plants within half a mile. By keeping larvae he was able to satisfy himself that the life-history extends over two years.

Mr. and Mrs. R. George took males flying about at night near Loxton on a rainy night in March.

CATOXOPHYLLA CYANAUGES Turner

Male—Head and thorax smooth-scaled, dark fuscous, with a dark blue sheen; thorax with collar, inner half of tegulae, and lateral parts white; antennae strongly bipectinate with short filamentous tip. Abdomen greyish-black; posterior margins of segments and a dorsal longitudinal band white. Forewings fuscous with short transverse black strigulae, ground colour paler near apex and near termen. Hindwings dark fuscous, darkest near base and tornus; a wide white costal streak. Forewings length 36 mm.; expanse 83 mm.

Female—Head small, fuscous; frons rounded, palpi just evident from above, antennae short, cylindrical, tapering; thorax fuscous with a deep blue sheen from some angles; an inverted U-shaped black mark; abdomen dark fuscous with some white scales near posterior extremity.

Brachypterous—Forewings dark fuscous with black strigulae, largest on basal half of costa and near inner margin. Hindwings darker with obscure traces of strigulae.

Estimated wing length 37 mm.; estimated expanse 90 mm.; total body length 84 mm.

Locality—Western Australia: Toodyay, Bencubbin. (Type, a male in Turner collection at Entomological Division, C.S.I.R.O., Canberra.) South Australia: Blinman, 4 March 1907 (female), Miller Creek (female), Barmera, January 1935 (female). Central Australia: locality not stated but probably near Everard Range. (Male described above and the allotype female I. 19097 in South Australian Museum.) New South Wales: Broken Hill.

The female of this species has not previously been described, although specimens have been held in collections for some years. Researchers seemingly have been reluctant to regard them as more than defective specimens in which the wings have not expanded. With greater knowledge of their life-history it is clear that the brachypterous condition is normal in the females of some members of at least two Australian genera, *Catoxophylla* and *Xyleutes*.

The mating pair described above as from Central Australia were taken together by Capt. S. A. White in the general vicinity of the Everard Ranges. There is great disparity in the bulk of the two sexes, although this is exaggerated in the figure by the differences in scale of the drawings shown. The female had newly emerged from the ground in the vicinity of an *Acacia* shrub, the species of which is not indicated. Wings of the females are very brittle and tend to break off transversely during life, so that it is exceptional to find an example with more than the basal halves of the wings present. In the drawing (fig. 4 d) one wing is shown as often found and the other as if perfect; it must be remembered that the latter condition is exceptional and untrue save at the time of emergence and it is only by pooling data on the several available female specimens that it has been possible to prepare the restored wing condition as shown. The males are of powerful flight. Their wings are not brittle. The genus has been separated from *Xyleutes* on the basis of the narrow pointed wings and the relatively smooth clothing of the thorax and abdomen.

There is great range in size in the females. The Blinman example is much smaller with a wing expanse of 20 mm. and total body length of 55 mm. The broken-off wings had been retrieved and are preserved with it. The Broken Hill female was found mating in the vicinity of *Acacia* shrubs, but the male was not preserved.

Among the Wailpi tribes people of the Northern Flinders Ranges the female moths are known as *ango* and when they appear in March and April are relished as food.

Fig. 1 Children digging grubs from roots of a witjuti (or witchety) bush *(Acacia kempeana)* in the Musgrave Ranges, South Australia.

Fig 2 Young man digging for Cossid grubs of the rolypoly bush *(Salsola kali)*, near Arukalanda, Western Musgrave Range, South Australia.

GENERAL DISCUSSION

A striking fact about the life-history of each of these Cossid moths and also of the desert-frequenting Hepialid *Trictena argentata* is the manner in which they have been able to adapt themselves to a life in the desert in spite of their relatively great inability to withstand desiccation. The larvae feed on roots well supplied with moisture, living in tunnels of silk in which the humidity is seemingly high since the exposed sap-laden layers of the root are exposed within it; the pupae remain sealed in the silken tunnels until they emerge as moths in late summer, either after rain has fallen or when the air is damp with dew. Only then do they lay eggs, renewing the cycle. Having no mouth parts this adult life is very brief. The duration of egg life is uncertain. In the case of *Trictena* the minute eggs emerge after only four days and the larvae burrow underground while the soil is still damp. The moths therefore are not so much desert-loving insects as ones which have been able to find and conduct their high-moisture requiring life-cycle, in one or other of the rare niches where constant moisture conditions can be maintained in spite of the generally prevailing aridity. It is not surprising therefore that the desert-dwelling *Trictena argentata,* which feeds on *Eucalyptus* tree roots, is equally at home where the conditions are ultra-moist, as in the wetter parts of Tasmania. However, the brachypterous Cossids here described are probably more discriminating in their requirements and may prove to occur only where their food plants are at home in sandy ground and where the annual rainfall is less than about 15 inches. The fully winged *X. leucomochla* has been taken at Cunderdin in the wet districts of Western Australia.

The cause of brachyptery in the females of these desert-frequenting moths is a matter for speculation; it is to be noted that they are very heavy-bodied and probably lay much larger numbers of eggs than do some of the species inhabiting more humid areas.

The presence of these brachypterous moths even in the heart of the Great Western Desert— for I have seen them dug out at the Warburton Range, the Mann Range and south of it as well as in the Everards, the Western MacDonnell Ranges and the Ngalia plain—may be an indication that over a long period of time the desert has not been unduly subjected to aridity much beyond that now prevalent.

The still undetermined Cossid larva which lives in the roots of the tumble weed or rolypoly bush (*Salsola kali*), whose adult is not yet identified, has a similar life-history, and in like manner is eaten by the aborigines in the Western Desert. When searching for the larvae they sweep a digging stick across patches of the drying weeds, readily breaking off those in which larvae are at work.

The larvae of this species must be rather more capable of desiccation, since they are to be found in the roots of quite dried-up rolypoly bushes. In some areas it is evident that the larvae of these moths are one of the causes of the breaking off of the shrub to become a tumble weed. When this happens the larvae seal over the remaining part of the root-stock to form their pupal chamber.

FISH OTOLITHS FROM THE PLIOCENE OF SOUTH AUSTRALIA

BY F. C. STINTON (COMMUNICATED BY N. H. LUDBROOK)

Summary

Otoliths of a new fossil species Sillago pliocenica are described from Pliocene sands underlying the Adelaide Plains. The otoliths suggest that the fish is more closely related to an Indo-Pacific species than to the species living in South Australian waters today.

FISH OTOLITHS FROM THE PLIOCENE OF SOUTH AUSTRALIA

By F. C. Stinton *

(Communicated by N. H. Ludbrook)

[Read 9 October 1952]

567.5 (942)

SUMMARY

Otoliths of a new fossil species *Sillago pliocenica* are described from Pliocene sands underlying the Adelaide Plains. The otoliths suggest that the fish is more closely related to an Indo-Pacific species than to the species living in South Australian waters today.

INTRODUCTION

In a study of Tertiary fish faunas considerable difficulty is encountered when systematic classification of the Teleostomi is attempted owing to the almost complete absence of skeletons. One is usually confronted with odd vertebrae, fin-spines, teeth, etc., which might be assigned to widely separated genera.

This difficulty may be largely overcome by a study of the fish otoliths which are usually found associated with the other isolated fragments. These objects show distinct determinative features which enable exact generic identification to be made by comparison of the fossil with analogous living forms. Although all teleosteans are provided with three pairs of distinct otoliths known respectively as the sagitta, lapillus, and astericus, the sagitta is usually the only one of use in diagnosis. Apart from lapilli of the Ariidae, it is the only type of otolith so far known in the fossil form. It may be mentioned that in the Ostariophysi and Cyprinodontes the asteriscus is the predominant otolith, while the lapillus is the principal otolith in the Siluridae.

The morphology of the inner face of a sagitta otolith is shown in fig. 1, which will elucidate its characteristic features.

The otoliths described in this paper were obtained from borings into the Dry Creek Sands underlying the Adelaide Plains. They were submitted to the writer by Dr. N. H. Ludbrook, who has drawn the figures and revised the paper for publication.

SYSTEMATIC DESCRIPTION

Phylum **CHORDATA**

Section CRANIATA

Subphylum **PISCES**

Class **ACTINOPTERI (TELEOSTOMI)**

Order PERCOMPRPHI

Suborder PERCOIDEA

Division PERCIFORMES

Family SILLAGINIDAE

Genus SILLAGO Cuvier, 1817

Sillago Cuvier, 1817, Regne Animal, 2, 258

Type species Sillago acuta Cuvier

Sillago pliocenica sp. nov.

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* Bournemouth, England.

Description of Holotype—Adult right sagitta otolith. Shape ovate, slightly produced posteriorly; inner face convex, outer face concave. Dorsal rim rounded and somewhat depressed; posterior and anterior rims nearly vertical; ventral rim rounded; all rims smooth. Inner face smooth with a horizontal sulcus running parallel with and close to the dorsal rim. The sulcus is completely enclosed, just touching the anterior rim but not opening on it. It is divided into an ostium and a cauda by a lower angle and a slight notch on the crista superior, the ostium being approximately one-third of the length of the sulcus. The cauda is narrower than the ostium and is somewhat bulbous at its extremity. The sulcus is nearly

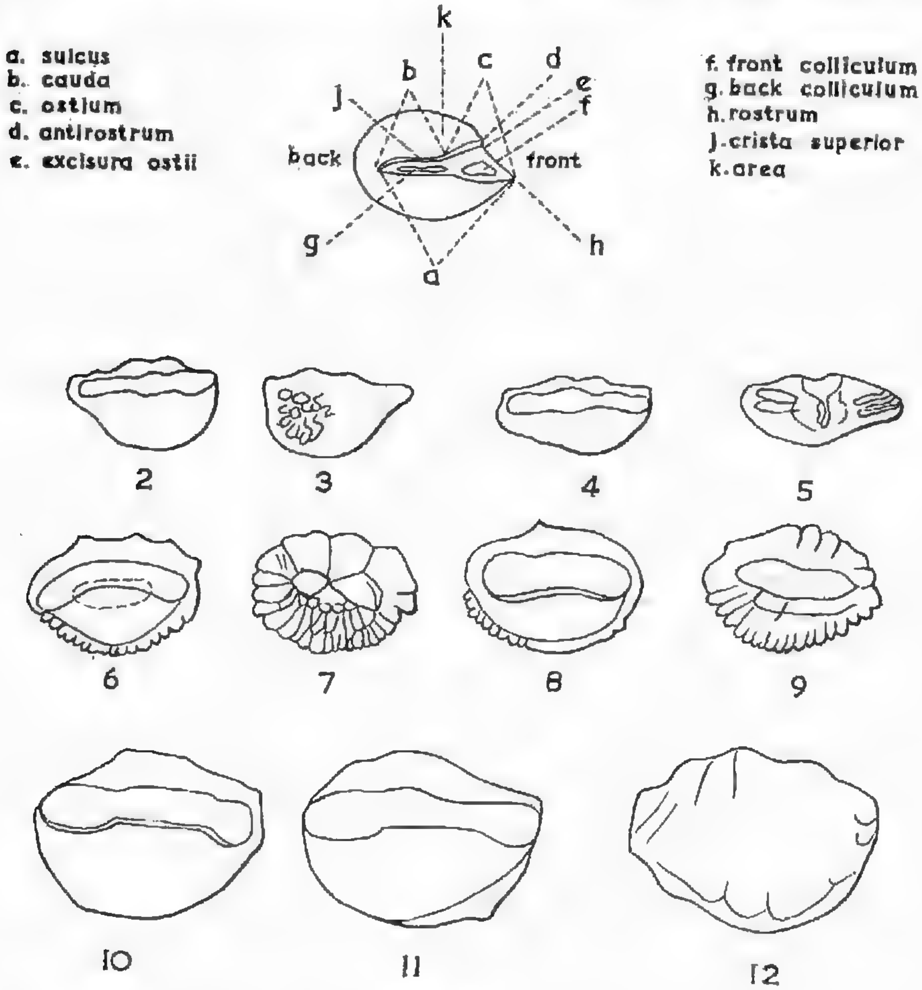

Fig. 1-12

Fig. 1, inner face of sagitta otolith, showing morphological features; fig. 2, *Sillago sihama* Forskål, inner face, X 5; fig. 3, *Sillago sihama* Forskål, otolith, outer face, X 5, fig. 4, *Sillago bassensis* Cuvier and Valenciennes, otolith, inner face, X 2; fig. 5, *Sillago bassensis* Cuvier and Valenciennes, otolith, outer face, X 2; fig. 6, *Sillago pliocenica* sp. nov., otolith, paratype 1, inner face, X 10; fig. 7, *Sillago pliocenica* sp. nov., otolith, paratype 2, outer face, X 10; fig. 8, *Sillago pliocenica* sp. nov., otolith, paratype 2, inner face, X 10, fig. 9, *Sillago pliocenica* sp. nov., otolith, paratype 2, outer face, X 10; fig 10, *Sillago pliocenica* sp. nov., otolith, paratype 3, inner face, X 7; fig. 11, *Sillago pliocenica* sp. nov., otolith, holotype, inner face, X 7; fig. 12, *Sillago pliocenica* sp. nov., otolith, holotype, outer face, X 7.

filled with colliculi, so that it is almost flush with the surrounding area of the otolith. No rostrum or antirostrum is present.

The character of the outer face changes as the otolith reaches a mature state, and the radial ridges and central tuberosities of the juvenile are obscured by deposition of calcium carbonate, producing an almost smooth surface marked merely by a few indistinct vertical ridges.

Dimensions—Length 5·41 mm., width 4·03 mm.

Paratypes—Juvenile right and left sagitta otoliths. In the juveniles the rims are denticulated, not smooth as in the adult. Outer face with well-marked radial ridges and central tuberosities.

Dimensions—Paratype 1 (fig. 6, 7), length 2·67 mm., width 1·9 mm. Paratype 2, length 2·88 mm., width 2·11 mm.

Material—The holotype (fig. 11, 12), Abattoirs Bore; paratypes 1 (fig. 6, 7), 2 (fig. 8, 9), Tennant's Bore, Salisbury; 3 (fig. 10), Abattoirs Bore; eight paratypes Hindmarsh Bore 450 ft. - 487 ft.; four paratypes Abattoirs Bore; four paratypes Weymouth's Bore 310 ft. - 330 ft.; six paratypes Tennant's Bore; all Dry Creek Sands, Pliocene.

Location of Types—Tate Museum Collection, University of Adelaide, with the exception of Hindmarsh and Weymouth's Bore paratypes, which are in the collection of the South Australian Department of Mines.

Observations—Comparison of these otoliths with examples from living specimens shows conclusively that they belong to a species of *Sillago*. They are closely allied to the East Indian *Sillago sihama* Førskal, and are less closely allied to the indigenous *S. bassensis* Cuvier and Valenciennes of South Australia, which has relatively longer and narrower otoliths while bearing a superficial resemblance to the fossil forms.

With a view to ascertaining the possible use of otoliths as index fossils the writer has sorted out many thousands of otoliths from most of the British Eocene and Oligocene beds, but has come to the conclusion that they appear to have too wide a stratigraphical range to serve any useful purpose. Considering the tropical affinities of the Dry Creek Sands fauna, the relationship between the otoliths from this Formation and the Recent Indo-Pacific species is worthy of some comment.

ACKNOWLEDGMENT

The writer is indebted to Mr. H. M. Hale, Director, South Australian Museum, for specimens of *Sillago bassensis*, and to Dr. E. Trewavas, Department of Zoology, British Museum (Natural History) for an example of *Sillago sihama*.

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AUSTRALIAN CUMACEA NO. 18

NOTES ON DISTRIBUTION AND NIGHT COLLECTING WITH ARTIFICIAL LIGHT

BY HERBERT M. HALE

Summary

This paper describes an experiment in collecting Cumacea at Garden Island, Western Australia. An electric globe of low candle-power, attached in the centre of the mouth of a tow-net, was lowered to the bottom, on the same spot, at regularly spaced time intervals, throughout one night, and remained immersed before each haul for 15 minutes. The peak period for the congregation of Cumacea at the lamp occurred at 2 a.m.; the results are discussed in some detail. The distribution of Australian Cumacea is also recorded.

AUSTRALIAN CUMACEA
No. 18

By HERBERT M. HALE *

NOTES ON DISTRIBUTION AND NIGHT COLLECTING WITH ARTIFICIAL LIGHT

[Read 9 October 1952]

595.381 (94) : 579.61

Fig. 1-3

SUMMARY

The paper describes an experiment in collecting Cumacea at Garden Island, Western Australia. An electric globe of low candle-power, attached in the centre of the mouth of a tow-net, was lowered to the bottom, on the same spot, at regularly spaced time intervals, throughout one night, and remained immersed before each haul for 15 minutes. The peak period for the congregation of Cumacea at the lamp occurred at 2 a.m.; the results are discussed in some detail.

The distribution of Australian Cumacea is also recorded.

INTRODUCTION

One hundred and sixty species of Cumacea are now recorded from shallow waters off the west, south and east coasts of Australia; very little is known of the Cumacea of the north coast.

Fig. 1 shows the specific representation of three families; the greatest number of species (sixty) is found in the Bodotriidae. The Leuconiidae and Lampropidae, with three and two Australian species respectively (four from the east coast and one from the south) are not included.

The diagram, of course, is in no way a quantitative index. It appears certain that individually the Bodotriids are predominant and that of the three families the Diastylidae play a relatively minor part.

In number of species the Bodotriids outstrip each of the other two families on the Indian Ocean and southern Australian coasts, but on the Pacific side the Diastylids are equally well represented, largely because of the numerous small forms referred to *Gynodiastylis* and allied genera.

On the evidence of material collected to date, the greatest speciation in all families has occurred on the Pacific Coast, particularly in the areas near rivers, while the south coast has produced the fewest species; it is to be borne in mind, however, that the large southern stretch of the Great Australian Bight has not been investigated for Cumacea, although it seems unlikely that many additional records will result from shallow-water collecting there.

NIGHT COLLECTING WITH UNDERWATER LIGHT

It is known that Cumacea are attracted by artificial light at night (Fage, 1933, 1945, etc.; Foxon, 1936, p. 378; Hale, 1943, p. 337). The use of a submerged light during the hours of darkness has proved a useful method of collecting these crustaceans, other marine invertebrates and fishes (Fage, 1927, p. 25, 1933, p. 107, etc.; Sheard, 1941, p. 12). It should be emphasised that in our experience use of a lamp of low candle power (about 2·5) results in more effective catches of Cumacea than does employment of a brilliant light. Gilbert

* Director, South Australian Museum.

C. Klingel, in his book "Inagua" (London, 1942, p. 297), states that, working in Chesapeake Bay, he prepared a 5,000-watt assembly, with which he hoped to attract a vast assortment of marine life to his observation post. He found that while his installation improved visibility, little came to its beam, so he resumed his "old method of using flashlights, which was much more satisfactory."

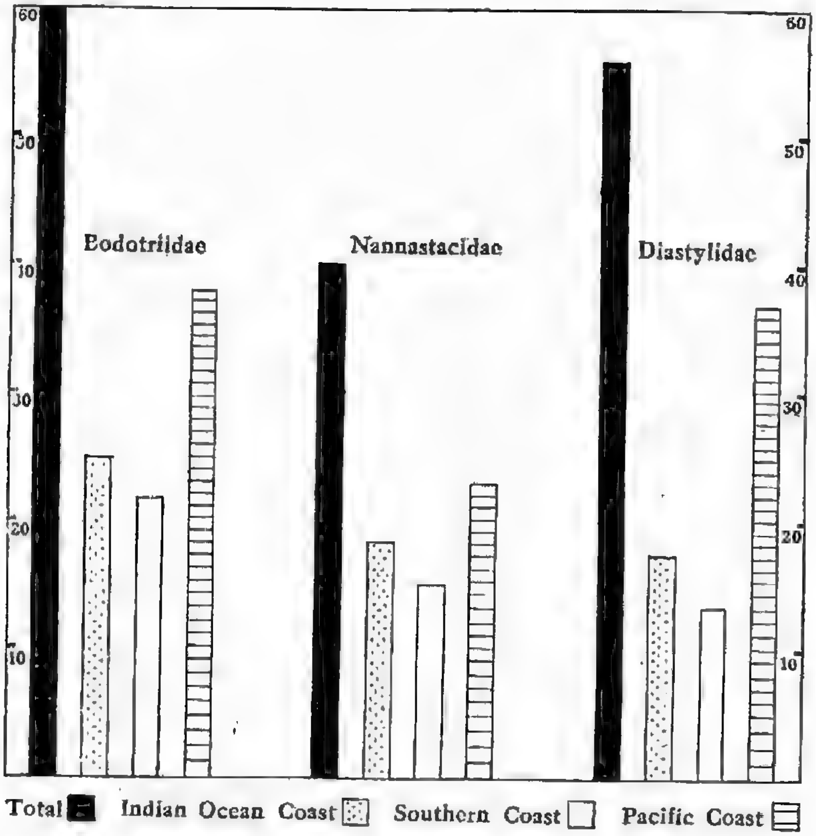

Fig. 1
Distribution of Australian Cumacea; the columns represent numbers of species.

Of the Australian littoral species of Cumacea, 19 per cent. have been secured by submarine light traps and by no other method. Some time ago doubts arose as to whether this means of obtaining material provided a true representation, as selectivity, time of operation, tides and other factors might operate. One may state at once, however, that 37 per cent. of the species taken by trawl and dredge have been attracted to lights also, so that nearly half of the Australian species collected to date are known to respond, and this notwithstanding the fact that underwater lights have not been very long utilized for obtaining Cumacea in Australian waters, nor have they been used in all areas investigated there.

As a result of our discussions, Dr. A. G. Nicholls, with the assistance of some of his students in the Biology Department of the University of Western Australia, undertook a regular series of submarine light hauls throughout a single night. The experiment was conducted on 26-27 November, 1946; a tow-net, with a lamp of low candle-power hung in the mouth as described by Sheard (1941, p. 13), at each hour from 6 p.m. to 6 a.m., was lowered to the sandy bottom

and left undisturbed for fifteen minutes. The net was operated from a jetty at Careening Bay, Garden Island, Western Australia, in three fathoms of water; the small tidal rise or fall on this part of the Australian coast (two to three feet) is considerably modified by on-shore and off-shore winds. The net was placed in exactly the same spot for each haul, as far as was practicable under working conditions.

On the night of the experiment the moon was in its first quarter—the new moon occurring on 24 November at 1.24 a.m., and first quarter on 2 December at 5.47 a.m., Western Australian standard time. Sunset occurred at 7.5 p.m. on 26 November and sunrise at 5.6 a.m. on the following day. There was a clear sky until the early hours of the morning of 27 November, when light clouds appeared. The night commenced with a strong easterly breeze, which died down later, and Dr. Nicholls noted that so much detritus was raised from the bottom by violent wave action that the range of the light was materially affected; on the other hand this factor may have been responsible for disturbing a greater number of burrowing animals than would have obtained otherwise.

High tide slack occurred between 6 p.m. and 7 p.m., but this period was increased by the easterly breeze which tended to bank up the water in the bay. The tidal run-off was retarded and the tide was not ebbing strongly until about 8 p.m. The first period of ebb was completed by 10 p.m. and then followed a long period of slack mid-water until about 3 a.m., when the ebb was completed. Low tide was at about 5.6 a.m. and the tidal range was two feet nine inches.

No Cumacea were present in the net after fifteen minutes immersion during sunset and again three-quarters of an hour later, and were absent also in two nettings made during sunrise and an hour after. In so far as Cumacea are concerned effective catches occurred only between 8 p.m. and 4.15 a.m., when nine hauls produced more than five thousand Cumaceans, representing twelve genera of three families—as well, of course, as a great many other Crustacea and other invertebrates.

The writer is greatly indebted to Dr. Nicholls, who later separated all Cumacea from the mass of material in each catch. The writer then sorted out the various species; several new forms were represented and have been described (Hale, 1948, 1949 and 1951). The twenty-seven species secured are as follows:

Family BODOTRIIDAE

Cyclaspis pura Hale
Cyclaspis juxta Hale
Cyclaspis nitida Hale
Cyclaspis sheardi Hale
Cyclaspis mollis Hale
Cyclaspis mjobergi Zimmer
Cyclaspis fulgida Hale
Eocuma agrion Zimmer
Vaunthompsonia nana Hale
Leptocuma nichollsi Hale
Glyphocuma serventyi Hale
Gephyrocuma repanda Hale

Family NANNASTACIDAE

Nannastacus inflatus Hale
Nannastacus subinflatus Hale
Nannastacus inconstans Hale
Nannastacus clavatus Hale
Nannastacus nichollsi Hale
Nannastacus vietus Hale
Cumella similis Fage
Cumella cana Hale
Schizotrema aculeata Hale
Schizotrema leopardina Hale
Schizotrema resima Hale

Family DIASTYLIDAE

Dimorphostylis cottoni (Hale)
Anchistylis waitei (Hale)
Gynodiastylis turgida Hale
Gynodiastylis inepta Hale

Dimorphostylis vieta Hale is the only species not listed above which has been taken in other collections made at Garden Island, and this is represented by a single female (G. P. Whitley, submarine light, 19 July 1945).

The hourly catches of Cumacea secured during this night collecting experiment are shown in fig. 2. Only about one hundred individual Diastylids were taken; this number is too small to be of much significance, but nevertheless the incidence of members of the family shows a gradual increase from 10 p.m. until the 2 a.m. haul, at which approximately half the total specimens of Diastylidae were secured.

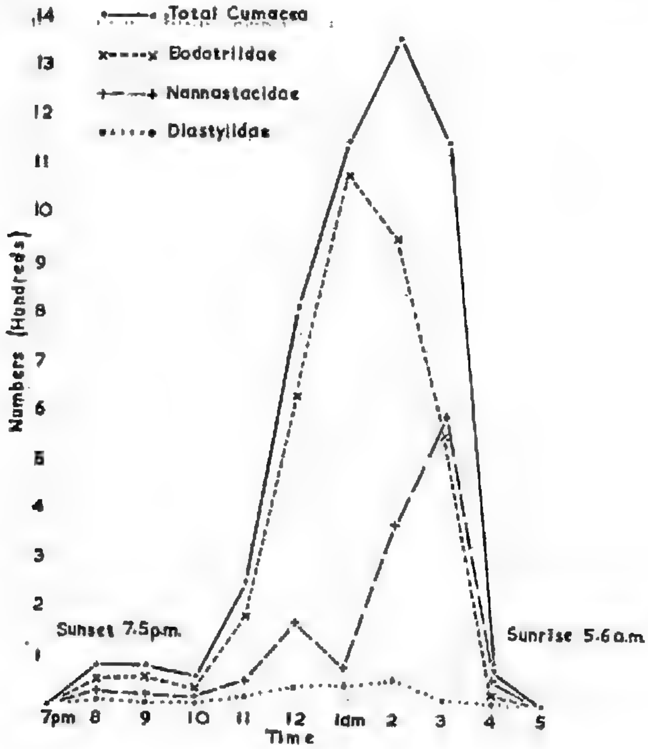

Fig. 2

Periodic variation in abundance of Cumacea attracted to underwater light at night.

The most productive nettings occurred between 11 p.m. and 3.15 a.m. The proportions of the most abundant species are:—

Cyclaspis pura Hale - - - -	69·7 per cent.
Other Bodotriids - - - -	1·8 ,, ,,
Nannastacus subinflatus Hale - - -	5·3 ,, ,,
Nannastacus inconstans Hale - - -	8·8 ,, ,,
Schizotrema leopardina Hale - - -	7·1 ,, ,,
Other Nannastacids - - - -	5·2 ,, ,,
Diastylids - - - - -	2·1 ,, ,,

Cyclaspis pura, represented mainly by adult males, is dominant in *all* hauls made before 3 a.m., and as 97·5 per cent. of the Bodotriids are referable to this species the remaining members of the family made no appreciable difference to the graph for the family.

The Nannastacids, almost all of which are males, became prominent in the takings much later than *Cyclaspis*. The three species noted above, each represented by not less than 270 examples, together constitute 80·5 per cent. of the total for the family. At midnight Nannastacids were plentiful (fig. 2), but by 1 a.m. the

two most abundant species of *Nannastacus* showed a marked decrease (fig. 3). The *Cyclaspis pura* males were then increasing and coincident with the sudden falling off of this species at 2 a.m. and 3 a.m. the *Nannastacids* increased in number, reaching their peak occurrence at 3 a.m. (at which time they slightly outstripped the Bodotriids), declining in the next haul, one hour before sunrise, almost to vanishing point (cf. Fage, 1945, p. 174). The considerably increased representation of this family at 2 p.m. resulted in the peak Cumacean catch at that hour, when 945 Bodotriids and 380 Nannastacids were netted.

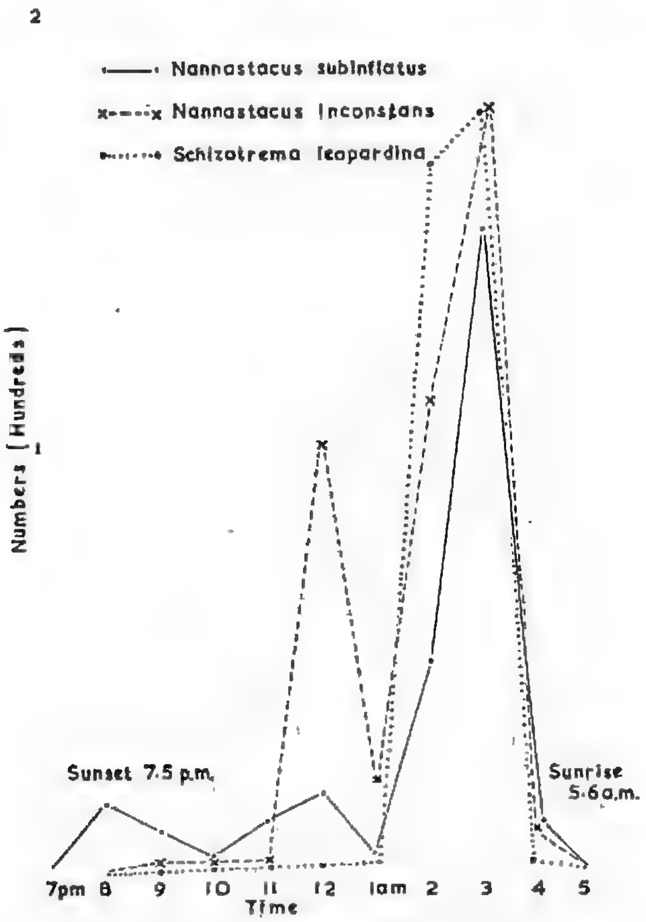

Fig. 3
Periodic variation in abundance of Nannastacids attracted to underwater light.

DISCUSSION

At the moment one has no means of judging whether or not the results of this fishing on the bottom furnish a real indication of the nocturnal activity of the Cumacea concerned; the following criticisms may be considered:—

(1) The possibility that all Cumacea found in the net had been stimulated by the light and that normally all would have remained quiescent.

Against this we have the well-known fact that shallow water Cumacea migrate to the surface during hours of darkness.

(2) It might be suggested that the catches consist partly of Cumacea which at the time of taking were normally active (*viz.*, in the initial stages of their

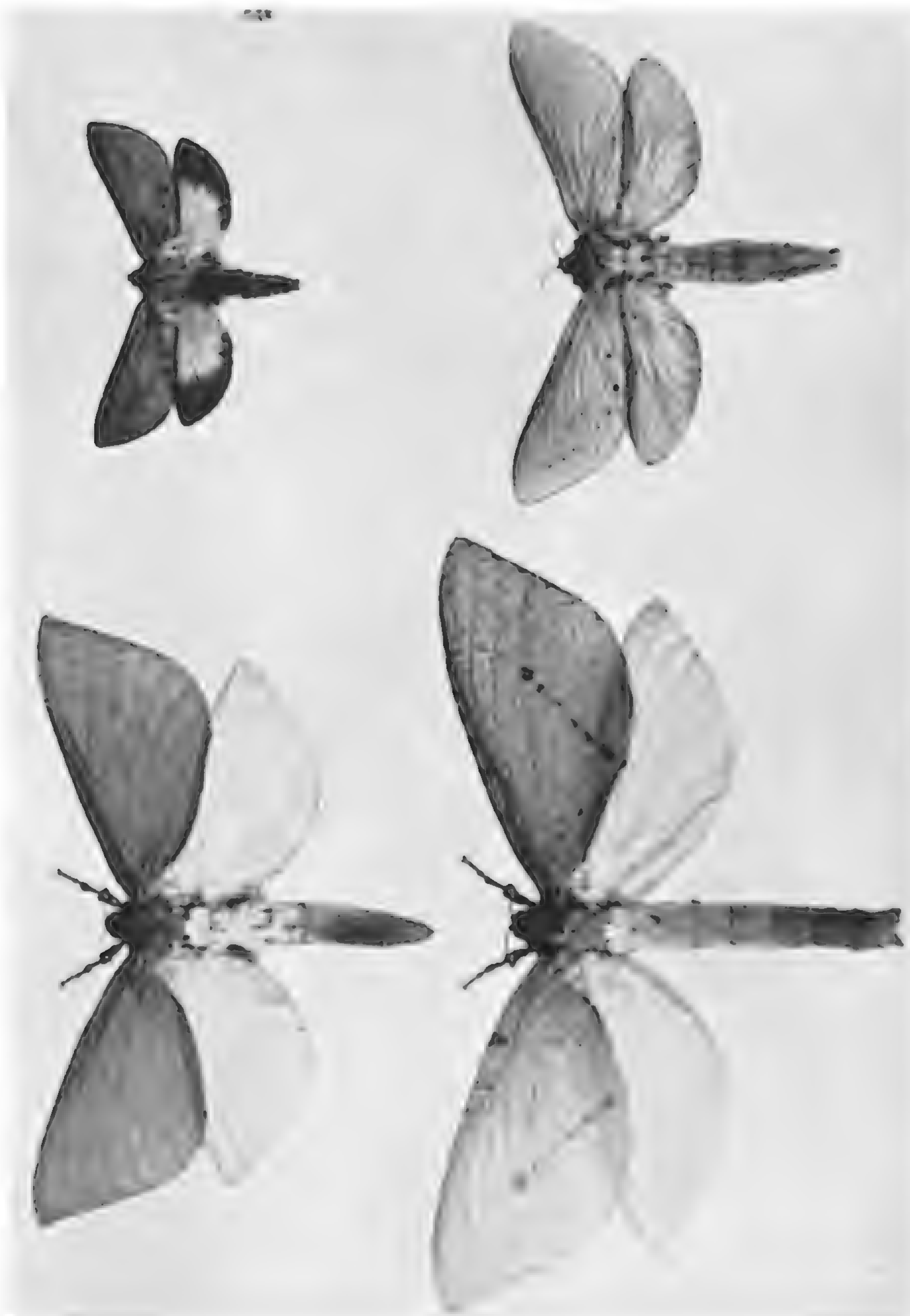

Fig. 1-2 *Oenetus scotti*
Upper left, male
Lower left, female

Fig. 3-4 *Oenetus paradiseus*
Upper right, male
Lower right, female

nocturnal vertical migration) and partly of individuals stimulated to activity by the light.

This theory could be employed to account for the marked preponderance of some forms throughout the series. Bodotriids predominate in the Garden Island collections; this family, however, is much more richly represented in the Indian and Pacific Oceans than it is in the Atlantic, and in Australian waters *Cyclaspis* in particular occurs almost everywhere where there is a sandy bottom. On the other hand *Anchistylis* and *Dimorphostylis*, sparsely represented at Garden Island on the night of collecting, have come to bottom lights in other Australian localities in abundance, and then may have been attracted during periods of normal night migrations.

(3) One must consider the possibility that an underwater light is a selective factor in that (a) some of the species more sparsely represented in the collections may be those which do not readily respond to light, or which may not be such active swimmers as the others; (b) males respond to the stimulus of light more readily than females.

For and against (a) is the fact that Cumacea which are relatively poor swimmers and are not normally active in great numbers (adult females of *Cyclaspis*, Hale, 1944, pp. 122 and 124), may be attracted on some nights to an underwater light of low candle-power in myriads, and that *Gynodiastylis* and allied genera have not been taken in quantity by any method—tow-net, Agassiz trawl or submarine light.

(b) As already noted, adult males far outnumber females and sub-adults in the material now under discussion and comprise about 90 per cent. of the individuals taken. Fage states that in the material examined by him the number of females collected at night without aid of a light is greater in proportion to that of males than when a light was employed. He suggests that the sexes may unite either below or to the side of the zone illuminated by the light. On the other hand one may mention *Cyclaspis sheardi*, a species widely distributed in southern Australia, ranging from lat. 34·0 S on the east coast to lat. 21·0 S on the west coast; the various methods of collecting used have, with one exception, resulted in the capture of adult males—many hundreds of them. One ovigerous female provided the exception and this was taken by underwater light. Again, as previously noted, there are indications that in at least one species of *Cyclaspis* the adult female, with soft exoskeleton, becomes active in considerable numbers at night and then may be attracted to artificial light near the bottom (Hale, 1944, p. 124). In *Nannastacus*, *Schizotrema*, and *Cumella*, males are much more commonly taken than are females in tow-net or dredge. Males usually predominate in submarine light collections of some Australian Diastylids, notably *Anchistylis* and *Dimorphostylis cottoni* (Hale), but on occasion recently moulted adult females are very much more abundant than males (Hale, 1945, p. 208). Females with ova in the marsupium far outnumbered males in a large number of specimens of *Anchistylis waitei* Hale which came to a submerged light at West Wallabi Island, Houtman Abrolhos group, Western Australia (G. P. Whitley, 9·40-10·40 p.m., 2 fath., Dec. 1945).

(4) One final criticism presents itself, namely, that at Garden Island the stimulus of the artificial light may have had a cumulative effect, and that the peak takings represent the maximum concentration of Cumacea which had slowly made their way from the periphery of the area influenced by the light (see Foxon 1936, and Hale 1943). In other words, that the sudden decrease in numbers in the early hours of the morning means merely that the area had been "fished out" as far as Cumacea are concerned.

This would seem to be supported by the fact that the Nannastacids appeared in quantity later than the male Bodotriids, and began to decrease in number later

than was the case in the last-named. Another factor surely operates here, however, because one hour before sunrise when the sky began to lighten *all* Cumacea showed a sudden sharp falling off. Other facts against this depletion theory are: (a) the light was employed for only 15 minutes after each hour; (b) after applying this method of collecting for some years, Mr. K. Sheard is inclined to the belief that the best collections of Cumacea are secured during periods of slack and fairly quiet water. It must be borne in mind, however, that in the experiment with underwater light here detailed, data concerning the prevailing conditions are recorded for the first time.

REMARKS

It is certain that at least some of the 27 species of Cumacea taken at Garden Island during one night are represented by individuals which had interrupted their vertical migration to congregate round the light at the bottom, either near the beginning of their ascent, or even later, as Foxen (1936, p. 378) has shown that Cumacea have been made to swim downwards in response to the stimulus of light. In their case the submarine light has served to concentrate a cross section of normally active specimens and may provide more uniform results than tow-netting at night, although insofar as quantitative data are concerned the method is of doubtful value. On the other hand, some of the specimens attracted to the light might have remained inactive without its stimulus.

The experiment demonstrates that the employment of a bottom light, at intervals throughout a favourable night, and on the same spot, furnishes a quick and possibly fairly complete census of the littoral species of Cumacea present in a small area.

The details of the takings include much of interest and the above notes are presented in the hope that students with more leisure time for field work than the writer will carry out further investigations on local populations and nocturnal activities of Australian Cumacea.

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ON A NEW SPECIES OF OENETUS (LEPIDOPTERA, FAMILY HEPIALIDAE) DAMAGING EUCALYPTUS SAPLINGS IN TASMANIA

BY NORMAN B. TINDALE

Summary

A new moth of the family Hepialidae, Oenetus paradiseus Tindale, is described from Tasmania, where it has been found causing some damage to Eucalyptus saplings. The harm is accentuated by the injuries caused by black cockatoos (Calyptorhynchus funereus), when they are feeding on the larvae and pupae of the moth.

ON A NEW SPECIES OF OENETUS (LEPIDOPTERA, FAMILY HEPIALIDAE) DAMAGING EUCALYPTUS SAPLINGS IN TASMANIA

By Norman B. Tindale *

595.787 (946)

SUMMARY

A new moth of the family Hepialidae, *Oenetus paradiseus* Tindale, is described from Tasmania, where it has been found causing some damage to *Eucalyptus* saplings. The harm is accentuated by the injuries caused by black cockatoos (*Calyptorhynchus funereus*), when they are feeding on the larvae and pupae of the moth.

Interaction of moth and cockatoo evidently plays an important part in the natural culling of sapling eucalypts.

A second race of the same species, *Oenetus p. montanus* Tindale, is recorded from snow gums (*Eucalyptus niphophila*) on Mt. Gingera in the Federal Capital Territory.

INTRODUCTION

In September, 1952, Mr. L. W. Miller, Chief Entomologist of the Department of Agriculture, Hobart, submitted to me for identification a male and two females of a Hepialid moth which had been bred from *Eucalyptus* seedlings at Taranna, Tasmania. Researchers of the Commonwealth Forestry Bureau there have been making growth studies of Eucalypts under forest conditions. They have been employing plots carrying different population densities of trees.

To obtain the initial desired densities naturally regenerating saplings were thinned out, down to definite numbers per acre.

The Oenetus grubs were found to be present in numbers of the trees, and although the insects themselves did not seem to do enough damage seriously to affect tree growth, they were noticed to be particularly attractive to black cockatoos, *Calyptorhynchus funereus* Shaw, which are very common in the area. In getting the grubs out of the wood the cockatoos gouge out very large holes, often damaging the saplings so that they weakened and broke off during heavy winds. These injuries reduced the planned numbers of trees in the artificial thinning experiment, thereby incidentally drawing attention to the natural culling of *Eucalyptus* saplings effected by the interaction of the Hepialid grubs and the black cockatoos.

Oenetus paradiseus sp. nov.

Pl. vi, fig. 3-4

Male—Head small, eyes normal; antennae short, slender, tapering, smooth, brown; head and thorax smooth, clothed in dull green hairs, abdomen purplish-brown, fore- and mid-legs green, hind-legs purplish-brown with a tuft of yellow sex hairs. Forewings purplish-brown with traces of darker brown markings and some scattered tufts of not very noticeable dull green scales usually forming a series of patches in the central portion of the wing; cilia very short, concolorous with rest of wing. Hindwings with basal two-thirds brilliant red, apex and termen broadly, and area at hinder angle and fringes less conspicuously, dull black; hairs at base of wing and base of abdomen red. Wings beneath bright red on basal half, distally dull black. Forewing length 24 mm., expanse 54 mm.

Female—Antennae similar to those of male, but shorter; head and thorax bright green; abdomen towards apex bright bluish-green, changing to a dull fawn

* S.A. Museum.

near base, with basal hairs almost pink. Forewings bluish-green with a marginal band of pale pink from apex to inner margin, also two transverse rows of pink spots from just below apex to inner margin at one-half. Hindwings salmon pink, lighter towards termen, with a marginal band of dull fawn at inner angle. Forewing length 35 mm.; expanse 77 mm.

Loc.—Tasmania: Ridgeway (Holotype, a male, dated 4 October 1948 and allotype female 12 October 1948, taken by J. R. Cunningham, in the Tasmanian Museum, Hobart; a paratype pair taken 4 October 1948, numbered I. 19099 in South Australian Museum; paratypes, from same locality, in collections of Messrs. J. R. Cunningham, F. E. Wilson).; also from Taranna (a paratype male and two females, emerged 28 August 1952, reared by L. W. Miller from larvae found boring in *Eucalyptus* saplings on 24 April 1952). Other examined specimens were a pair from Tasmania submitted by the late Mr. G. Lyell and two paratype females, labelled "Tasmania" formerly in the J. A. Kershaw collection and now passed to the National Museum, Melbourne; there is one male, without locality label, in the Queen Victoria Museum, Launceston.

There are four males and a female from Ridgeway, Tasmania, in the F. M. Angel collection, including a pair bred out on 15 September 1950; one taken 16 September 1950 by S. Angel, and two males dated 7 September 1949 taken by Miss M. Tagg.

Thirteen males, 11 females examined.

In the Taranna male, as also in one of the Ridgeway examples, the brown of the forewings is in certain lights tinged dull green. The Taranna females have the faded-scarlet markings of forewing rather larger than in some Ridgeway examples.

For colour contrasts this pair of moths is not equalled in the genus *Oenetus* and the colours themselves are most brilliant. Hence there is little need to apologise for *O. paradiseus* as the chosen name.

The male is distinctive by reason of its fiery red hindwings with broad black outer margins. The female is equally distinctive with its bluish-green forewings and pink or faded scarlet margins and spots.

The species falls into that section of the genus *Oenetus* in which the eyes of the males are not hypertrophied, but are of normal form and proportions, as in the female. In this character the species is most nearly related to *O. scotti* Scott, particularly resembling that species in the general shape of the wings; the colours and markings of course bear little resemblance.

A pair of *O. scotti* Scott, from Brisbane, Queensland are figured (pl. vi, fig. 1-2) for comparison with the new species. In *O. scotti* the head, thorax and extremity of abdomen are bright green, the forewings also are green with brown markings; the hindwings are yellow at tips, and pink towards base; the base of abdomen also is clothed in pink hairs and scales.

I am indebted to Mr. L. W. Miller for sending the material of *O. paradiseus* which stimulated the writing of this paper in its present form, and to Mr. J. R. Cunningham for the gift of the pair in the South Australian Museum collection.

In October 1948 Mr. J. R. Cunningham bred out both sexes of this species from pupae he found in *Eucalyptus* saplings at Ridgeway, Tasmania. The late Mr. George Lyell of Gisborne, at about the same time, sought my opinion as to the identification of specimens sent to him also from Tasmania.

The species was already known to me, for some years previously the late Mr. J. A. Kershaw had submitted examples of the species; his series consisted of two faded females, labelled merely as from "Tasmania". An example of the male, without locality label, was in the Queen Victoria Museum, Launceston.

The species appeared then to be new, and a preliminary description was drafted but put aside pending a general revision of the genus. At this time there

were several described species, of which the types are preserved in overseas Museums and of which authentically identified material was not locally available. In the intervening time much of the data for such a revision has been brought to hand and the study is well advanced.

The present paper anticipates the Revision in order to provide a name for the species, which thus suddenly has become of interest to the forester and of possible minor economic importance because of its association with cultivated forest Eucalypts.

The interplay of cockatoos and Hepialid grubs may be of importance to the forester elsewhere. Only a few days after the above paragraph was drafted Mr. I. F. B. Common, of the Division of Entomology, C.S.I.R.O., Canberra, wrote to me under date of 20 October 1952:—"About a fortnight ago I was intrigued to find that black cockatoos had been biting large pieces out of snow gum saplings near Mt. Gingera to obtain larvae and pupae of a Hepialid. A search revealed that pupae of the moth were quite common, and I have brought back a number of sticks to rear the adults. . . . I was wondering if you have any records of a species from snow gums at about 5,500 feet."

While this paper was going through the press, Mr. I. F. B. Common sent me for examination four males and four females of the Mt. Gingera form. These prove to be the same species but distinguishable, in the male, by the somewhat less fiery red colour of hindwings. This colour extends almost to the margins on the middle third of the wing instead of being separated from it by a rather wide black marginal band. The females usually tend to have a more noticeable greenish suffusion on the outer third of hindwing. This racially distinct form may be known as **O. p. montanus** subsp. nov. The specimens were reared from pupae gathered on Mt. Gingera, F.C.T., at 5,500 ft.; they emerged on 25 and 26 October 1952. The holotype male and allotype female have been returned, together with a paratype pair, to the C.S.I.R.O. Division of Entomology, Canberra, a paratype pair being retained for the South Australian Museum collection (I. 19100) and another pair for the British Museum.

Mr. Common writes:—"Although the moths emerged in late October in the laboratory, general observations in the field suggest that they probably emerge a week or two later at outdoor temperatures at that altitude. The damage to the tree trunks of the snow gums has been noticed at several localities along the Brindabella Range (of which Mt. Gingera is a part) above about 4,500 feet. Saplings with trunks from about ¾ inch to 3 or 4 inches are attacked and, again from general observations, I would say the larvae have at least a two-year (or perhaps even a three-year) life cycle. At the time the pupae were collected in mid-October, there were also quite immature larvae.

The exit hole is usually quite inconspicuous and is often at the base of and on the upper side of an upwardly oblique branch. Beneath the bark and around the exit hole a hollow of variable size is usually found. This is apparently eaten out by the larva. While the larva is still feeding, the exit hole is covered by a small amount of firm webbing into which is woven particles of wood". Mr. Common suggests that the amount of webbing is less than in species such as *O. daphnandrae* Lucas and *O. eximia* Scott and that in contrast with these species the plug formed when the larva is about to pupate is not a thin horizontal membrane of silk scarcely visible from outside the hole, but is a "plug clearly visible from without as a vertical or slightly oblique whitish silken membrane."

NOTE ON A TRIASSIC FISH FOSSIL FROM LEIGH CREEK, SOUTH AUSTRALIA

BY R. T. WADE (COMMUNICATED BY S. B. DICKINSON)

Summary

A fragment of a fossil fish of undetermined affinities for which a new genus and species, Leighiscus hillsi, are created is described from the Trias of Leigh Creek. It is the first Triassic fish to be recorded from South Australia.

NOTE ON A TRIASSIC FISH FOSSIL FROM LEIGH CREEK, SOUTH AUSTRALIA

By R. T. Wade

(Communicated by S. B. Dickinson)

[Read 13 November 1952]

567 (942-17)

SUMMARY

A fragment of a fossil fish of undetermined affinities for which a new genus and species, *Leighiscus hillsi*, are created is described from the Trias of Leigh Creek. It is the first Triassic fish to be recorded from South Australia.

Order indet.

Family indet.

Genus **Leighiscus** gen. nov.

Generic characters determinable from the caudal region only. Tail abbreviate-heterocercal, advancing towards homocercy, with upper fleshy lobe greatly reduced; neural and haemal spines slender rods with slightly expanded proximal heads. Lower part of tail with strap-like haemal elements. Vertebral centra unossified; fin rays having long proximal unjointed segments, distally divided and jointed; scales very thin.

Type species **Leighiscus hillsi** sp. nov.

Leighiscus hillsi gen. et sp. nov.

Holotype—Tate Collection, University of Adelaide, caudal fragment in counterpart. Reg. No. P2070.

Remarks—The specimen in counterpart is preserved in fine mudstone as a laterally compressed caudal region which is stained by oxide of iron.

Except that it is clearly not a Palaeoniscid, or Teleost, its systematic position cannot be determined. Because, however, it is the first Triassic fish reported from S. Australia it is necessary to record its occurence. Its state of preservation and the nature of the matrix suggest that deposits at Leigh Creek might be worked hopefully and profitably.

Description—The fragment preserved is the caudal region which extends from behind distal fragments of the last dorsal fin and the last few rays of the anal fin. Length to the base of the upper produced lobe is 90 mm., depth at the origin of the caudal fin is 40 mm. and at the preserved part of the anal fin 45 mm., so that a fairly slender fish is suggested.

The *tail* is abbreviate-heterocercal, with the upper fleshy lobe greatly reduced and probably quite short although its tip is not on the specimen.

Of the *endoskeleton*, the neural and haemal spines are preserved as casts filled with oxide of iron. Eight of the neural spines are easily observed as slender rods with slightly expanded proximal heads, and are on average about 12 mm. long. About eight or ten anterior haemal spines are similar in appearance to the neurals but a little longer and set more obliquely in the body. These are succeeded by about twelve haemal elements which are considerably flattened perhaps or expanded greatly distally. There are obscure indications of supports beneath the preserved dorsal and anal rays.

The *fins* are incompletely and imperfectly preserved. Of the dorsal fin, which seems to have been in advance of the anal, there are three fragments

of rays of the hindmost part of the fin and obscure impressions of two or three ray supports. Five rays of the hindmost end of the anal fin are preserved and they show no trace of jointing or branching.

The caudal fin, too, is incomplete. Ventrally at the origin of the fin there are two or three short sharp-pointed rays of increasing length, then in succession proximal segments of about eighteen well-spaced rays, which show division into joints only in the most posterior five. Very imperfect remains of more distal parts of the rays were almost certainly branched and divided into very small joints.

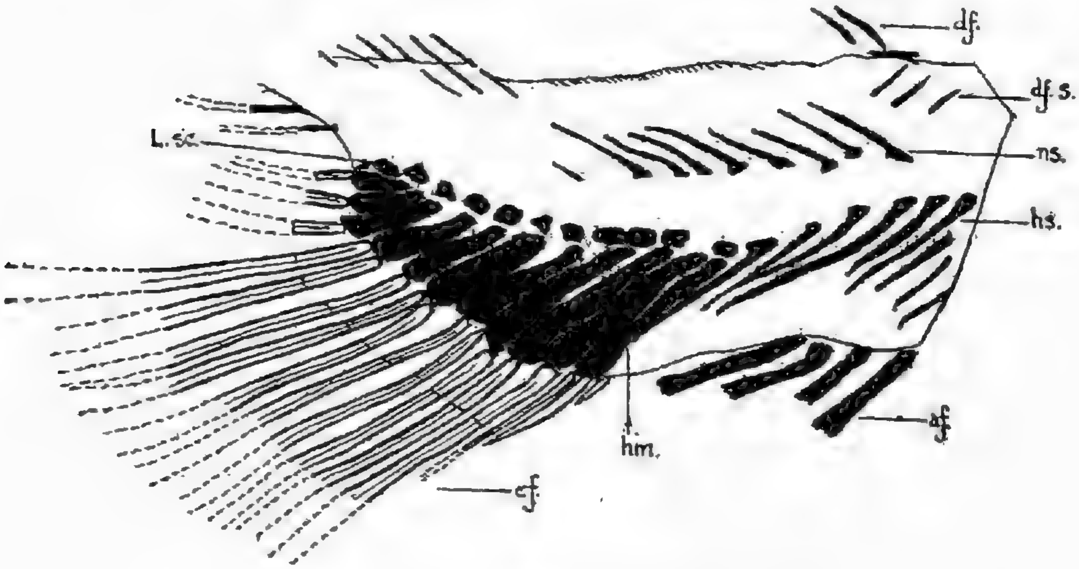

Fig. 1

Leighiscus hillsi sp. nov., Holotype, approximately natural size
Sketch, with very trifling reconstruction to act as key to photograph
af. Parts of several rays of the hindmost rays of the anal fin. *cf.* Part of the very incomplete caudal fin (jointing and dividing omitted). *df.* Two fragments of hindmost dorsal finrays. *hs.* Haemal spines. *hm.* Haemal elements, obscure proximally. *ns.* Neural spines. *L.sc.* Scales of lateral line (?). *df.s.* Dorsal fin spines.

On the upper margin of the upper lobe there is the origin of the dorsal section of the fin—five slender sharply pointed rays.

The *scales* if present must have been very thin—the vertebral spines show so clearly—but here and there, there are small oval markings, bearing concentric ridges or hollows, which suggest scales; whilst in a line towards the head from the base of the upper lobe there is a line of about nine fragmentary scute-like impressions which represent scales along the lateral line canals.

NOTE. The name *Leighiscus hillsi* is intended to record the locality where the specimen was found, and the interest of Professor E. Sherbon Hills, Melbourne University.

It is unfortunate that the complete fish was not collected. To the extent to which it is known it has little resemblance to any of the described Triassic fishes. The advance towards homocercy shown in the rounded extremity of the lower part of the tail with its strap-like haemal elements, seems to go beyond that of *Macroaeths* (Mid Trias) or *Belonorhynchus* (L. Trias) and to bear comparison with the Jurassic *Callopterus*.

A NEW GENUS AND SPECIES OF SPELEOGNATHIDAE (ACARINA) FROM SOUTH AUSTRALIA

BY H. WOMERSLEY

Summary

A new genus Boydaia (Acarina, Speleognathidae) is erected for certain species of mites hitherto placed in the Speleognathus Womersley, and a new species of Boydaia, (B. angelae) from the mucus of a frog's mouth is described from South Australia.

A NEW GENUS AND SPECIES OF SPELEOGNATHIDAE (ACARINA) FROM SOUTH AUSTRALIA

By H. Womersley *

[Read 13 November 1952]

595.42 (942)

SUMMARY

A new genus *Boydaia* (Acarina, Speleognathidae) is erected for certain species of mites hitherto placed in *Speleognathus* Womersley, and a new species of *Boydaia*, (*B. angelae*) from the mucus of a frog's mouth is described from South Australia.

In 1936 (Ann. Mag. Nat. Hist., (10), 18, 312), the author erected the family Speleognathidae for a very interesting new species of mite, *Speleognathus australis* Wom., found in moss and also on the surface of water in horse troughs at Glen Osmond in 1934 and 1935, by Dr. R. V. Southcott.

As all the specimens were females and from the habitat on horse troughs it was thought that in the early stages they may have been parasites in the nasal cavities of birds or cattle drinking at the troughs.

The swabbing of cattle and the examination of birds, however, failed to show any evidence of this, Further, in recent years the mites have not again been met with.

In 1948 (Proc. Ent. Soc. Washington, 50, (1), 9) Miss Elizabeth M. Boyd described another species, *S. sturni* from North America, found inhabiting the respiratory passages, but more frequently the turbinals than the trachea, of the starling, *Sturnis vulgaris* L. She also recorded it from a boat-tailed grackle *Cassidix mexicanus*. Both larvae and adults were found.

In her remarks Miss Boyd points out the close relationship of the Speleognathidae to the Ereynetidae (slug-mites), which differ in the absence of genital suckers and the posterior pair of sensory setae. Particularly did she stress the interesting fact that *S. sturni* inhabited warm, well-aerated mucous environments similar to the slimy secretions of slugs inhabited by species of *Riccardoella* of the Ereynetidae. Differences between *S. australis* and *S. sturni* were given as the presence in *sturni* of a 3-segmented palp instead of a single segment, and the absence of eyes.

The first of these characters warrants more than specific valuation, and I therefore now propose the new genus *Boydaia*, after Miss Boyd.

Genus **Boydaia** nov.

As in *Speleognathus* but with 3-segmented palpi. Mouthparts visible from above. Type *Speleognathus sturni* Boyd 1948

Recently I have received a single specimen of a Speleognathid collected from the mucus under the tongue of a frog, *Limnodynastes tasmaniensis* Gunther var. by Miss M. Angel of the Zoology Department, University of Adelaide, while searching for internal parasites.

Upon examination this specimen was found to have the mouthparts visible from above, a 3-segmented palp, and to lack eyes, thus agreeing generically with the species described by Miss Boyd. As, however, it differs specifically from *Boydaia sturni* (Boyd) it is described as follows as a new species.

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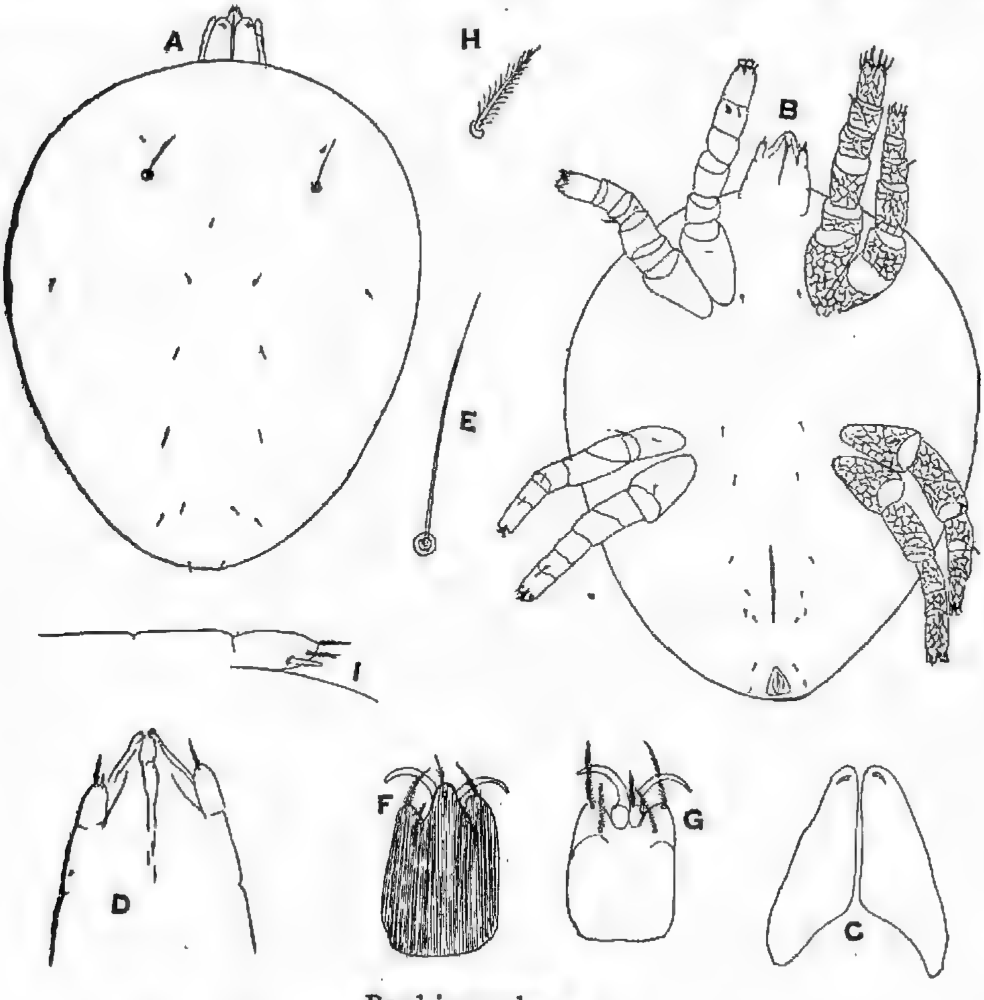
* South Australian Museum.

Boydaia angelae sp. n.

Description—Female. Colour whitish. Soft-bodied, without dorsal or ventral shields, cuticle with fine punctate striations. Egg-shaped, widest just in front of coxae III, length of idiosoma 580 μ, width 410 μ. Anus subterminal. Mouthparts protruding, visible from above, conical; mandibles relatively large basally, but chelicerae minute and hook-like; palpi apparently 3-segmented, but the first two segments internally ankylosed to rest of gnathosoma, terminal segment free



Boydaia angelae sp. n.

A, idiosoma in dorsal view; B, entire ventral view showing sclerotization of left legs; C, mandibles; D, gnathosoma from below; E, anterior sensory seta; F, tarsus I, dorsal; G, tarsus I ventral; H, leg seta; I, palp from below.

furnished with a terminal short ciliated seta, a similar but shorter seta ventrally and subapical and a ventral subapical plain sensory rod; no two pairs of minute setae on labial portion as shown for *B. sturni* have been seen. Legs short and stout, with six segments, longitudinally striated but under the cuticle with a strongly sclerotized network especially on the coxae; coxae in four pairs, legs I and II directed forwards, III and IV directed backwards, with few short ciliated setae; tarsi all apically bilobed, with paired claws, a median pad from which a short ciliated empodium arises ventrally, with a dorsal and a ventral ciliated seta

apically on each lobe, and a subapical pair of setae both dorsally and ventrally. Dorsally the idiosoma with an anterior pair of long, 42 μ, fine filamentous sensillae and nine pairs of very short ciliated setae. Ventrally with a pair of setae between coxae I, between coxae III, and between coxae IV, four on each side of genital slit and two on each side of anus. All the setae on legs, palpi and body are straight with short ciliations, and not oval and ciliated as in *B. sturni* or *Speleognathus australis* Wom.

Remarks

Differs from *B. sturni* (Boyd) in the sensillae being filamentous and not slightly clavate, in the partially ankylosed palpi, and the very differently formed leg and dorsal setae.

It is named in honour of Miss Madeline Angel who found the specimen.

A third species of *Boydaia* has recently been described (J. Parasitol. 38, (5), 1952) by Dr. D. A. Crossley, Jr., under the name of *Speleognathus striatus*. In the structure and form of the palpi, it will be better placed in the new genus proposed in the present paper. In addition, Crossley points out the presence of a pair of attenuate setae anterior to the genital opening in *S. australis*, which are absent in *B. striatus*, as they are also in *sturni* and *angelae*. These setae can be regarded as a secondary generic character of *Speleognathus*. The three species of *Boydaia* now known may be keyed as follows.

1 Eyes present, 1 + 1. Body both dorsally and ventrally conspicuously striated, as also are the legs and palpi .... *B. striatus* (Crossley)
  Eyes absent. Body and appendages without conspicuous striations.

2 All palpal segments free. Sensillae lightly clavate. All setae on palpi, legs and body short and clavate .... *B. sturni* (Boyd)
  Palpi with first two segments internally ankylosed with rest of gnathosoma. All setae on palpi legs and body straight with short ciliations .... *B. angelae* sp. n.

The hosts of *S. australis* are unknown but *B. sturni* has been found in the nasal passages of starlings (Boyd) and sparrows (Porter and Strandtmann) in America; *B. striatus* is recorded from the nasal passages of two species of doves from Texas and Georgia, U.S.A. (Crossley), while the new species herein described was from a frog.

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THE GENESIS OF SOME GRANITIC AND ASSOCIATED ROCKS IN THE NORTH-EASTERN FLINDERS RANGES, SOUTH AUSTRALIA

BY D. R. BOWES

Summary

The country rocks of the area, which are tillites, slates, quartzites and marbles of the Sturtian Series of the Adelaide System (Upper Precambrian) were involved in an early Palaeozoic orogeny. Some of the rocks were greatly changed and migmatite complexes consisting mainly of rocks of granitic composition were produced. Rocks with compositions more basic than that of any of the country rock were also formed. A period of dislocation metamorphism followed the migmatization and then a magmatic granite was intruded. Metasomatic activity associated with the late phases of cooling of this granite altered a dolomitic marble to talc in favourable structures. A long period of quietude and erosion followed until (?) early Tertiary times when some lacustrine beds were deposited. Later there was some isostatic adjustment with differential uplift of blocks of the crust and the deposition of outwash alluvium.

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D. R. Bowes *

551.72 (942–191)

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I. INTRODUCTION

(a) Location and Access

The area described in this paper is the north-eastern extremity of the Flinders Ranges (Fig. 1). To the north it is bounded by the alluvium of the Lake Eyre Plain (beneath which is the Great Artesian Basin), to the east by the Paralana fault and the alluvium of the Lake Frome Plain, while the southern and western margins are drawn so as to include the boundary of the Terrapinna Migmatite Complex and the talc deposits respectively.

Mount Fitton, which is centrally placed, is situated approximately 350 miles N.N.E. of Adelaide, its position being that of latitude 29° 55′ S and longitude 138° 25′ E (approx.). It is 85 miles by road in an easterly direction from Lyndhurst railway siding which is 392 miles north of Adelaide (by rail).

(b) Physiography

At the north-eastern extremity of the ranges the country flattens out towards the plains to the north and the east, and although hilly, with the highest points more than 1,000 feet above sea level, it lacks the steep slopes and rugged relief of the country around Freeling Heights and Mount Painter to the south. Many of the watercourses flow in broad valleys (Plate VIII Fig. 1) in contrast to the steep courses through rugged gorges of many of the creeks in the central part of the ranges.

* Department of Geology, University of Adelaide.

In and adjacent to the ranges the drainage lines are well defined. The main water-courses, the Hamilton, Mudnawatana, and Billy Springs Creeks, have their sources in the high ground to the south, and have cut deep gorges through the hills of the migmatite complexes. Extensive plains stretch both north and east of these ranges.

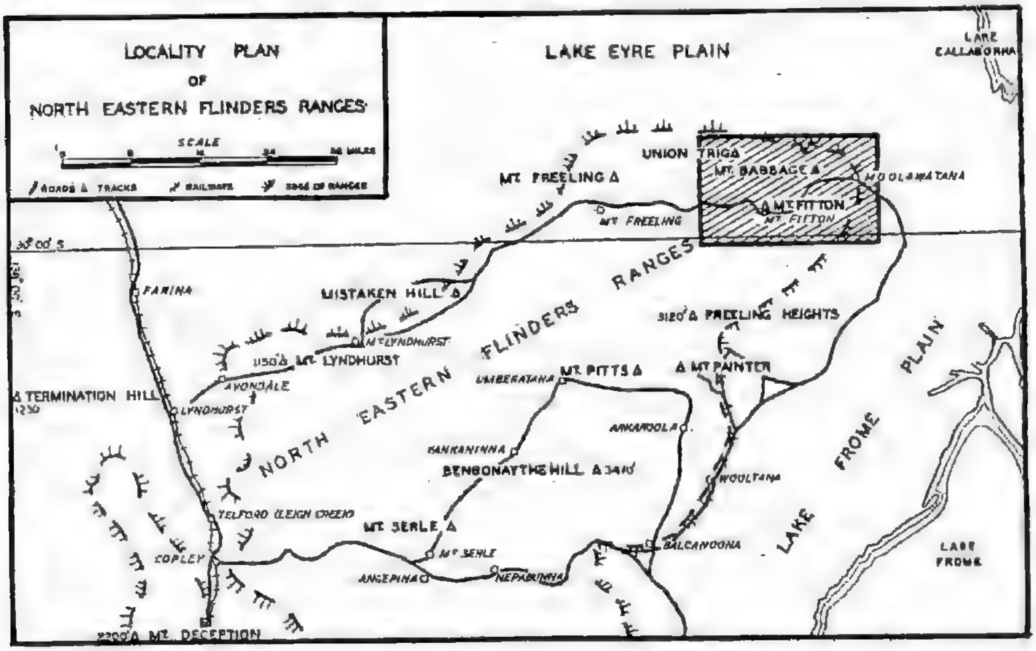

Fig. 1 Locality plan of north-eastern Flinders Ranges.

(c) Previous Investigations

The earliest report of any geological investigation in this part of South Australia was given by Woodward in 1885 in which he recorded the occurrence of glacial till and its gradual change to gneiss and granite. No further examination of these changes was made until 1946 when Sprigg (1951) conducted a reconnaissance survey of the area in connection with the talc deposits discovered west of Mount Fitton, but as early as 1887 the geological map of South Australia showed "Plutonic" rocks in the area. During the intervening years there had been some mining activity west and south of Mount Fitton, but there was no geological survey of the area round these mines.

Howchin (1924) correlated Woodward's boulder clay with the Sturtian Tillite [1] and later Howchin (1929) grouped it in the Adelaide Series[1] (Upper Precambrian) and grouped the gneisses and granites with the older Precambrian. Previously Woolnough and David (1926) had classed the gneisses and schists in the area as being part of the Willyama Series (Archean).

Since the discovery of talc in 1944, the area has become a focus of geological activity. Sprigg (1945 (a)) and Broadhurst (1946, 1947), made preliminary investigations. The detailed structure and ore reserves, regional structure, and petrology of the talc deposits were studied by Dickinson (1949), Sprigg (1949) and Stillwell and Edwards (1951), respectively, and Sprigg (1951) gave a brief account of the regional geology of the north-eastern Flinders Ranges.

(1) Now the Sturt Tillite of the Adelaide System (Mawson and Sprigg 1950).

(d) Present Investigations

The desirability of a detailed petrological investigation firstly of the granite terrain in close proximity to the talc deposits and secondly of the changes from tillite to gneiss and granite was suggested by Sprigg who made available a photo-geology map (on which Fig. 2 is based) and information obtained during a brief reconnaissance survey of the area. The field investigations were carried out during 1947 mainly under the auspices of the South Australian Department of Mines and the laboratory work was done in the laboratories of the Department of Geology, Imperial College, London, in 1948-9 during the tenure of an 1851 Science Research Scholarship. Further field and laboratory investigations performed during 1950-2 confirmed and amplified the original conclusions.

This paper gives an account of the metamorphic and igneous history of the area with particular reference to the genesis of the granitic rocks. Detailed accounts of the mineralogical and chemical changes involved in the migmatitic transformation of the various types of country rock are published separately (Bowes 1952 and 1953).

The specimen numbers referred to in the text are those of the Rock Catalogue, Department of Geology, University of Adelaide.

II. GEOLOGICAL SETTING, STRATIGRAPHY AND STRUCTURE

(a) Geological Setting

Investigations in the Mount Lofty and Flinders Ranges have demonstrated the existence, in late Precambrian and early Palaeozoic times, of a geosynclinal depression which stretched from south to north for several hundreds of miles and in which a vast thickness of sediments accumulated (Mawson 1947, Sprigg 1952). The late Precambrian sedimentary accumulation is known as the "Adelaide System" (David 1922, Mawson & Sprigg 1950) and the rocks composing most of the Flinders Ranges are the equivalents of these sediments. In the vicinity of Mount Fitton and Mount Painter these rocks were migmatized and also intruded by granite.

During late Mesozoic and early Tertiary times much of north-eastern South Australia was a basin of deposition and relics of the Eyrian Series (Woolnough and David 1926) are found as outliers at the north-eastern extremity of the Flinders Ranges where this basin overlapped the older rocks.

(b) Stratigraphy

(i) *Adelaide System.* Tillite, which Howchin (1924) considered the equivalent of the Sturt Tillite, makes up part of the country rock of the Mount Fitton area. Support for this correlation is given by the continuous outcrop of the tillite into areas further south where it is considered to be Sturtian by Sprigg (1945(b)) and Mawson (1949).

The stratigraphic sequence, commencing with the older sediments is as follows :—

Tillite series—tillite, laminated slate, metamorphosed siltstone and quartzite; some of the slates and siltstones contain erratics.

Tremolite Marble lens—a dolomitic marble.

Laminated Slate series—laminated and calcareous slates and metamorphosed siltstones with some tillite bands in the lower horizons; also minor dolomitic marbles.

Details of this succession are given by Sprigg (1951).

Apart from the presence of the marble lens, this stratigraphical sequence is similar to that of part of the Sturtian series of the Adelaide System near Adelaide (Mawson & Sprigg 1950) and in the Mount Painter area (Sprigg

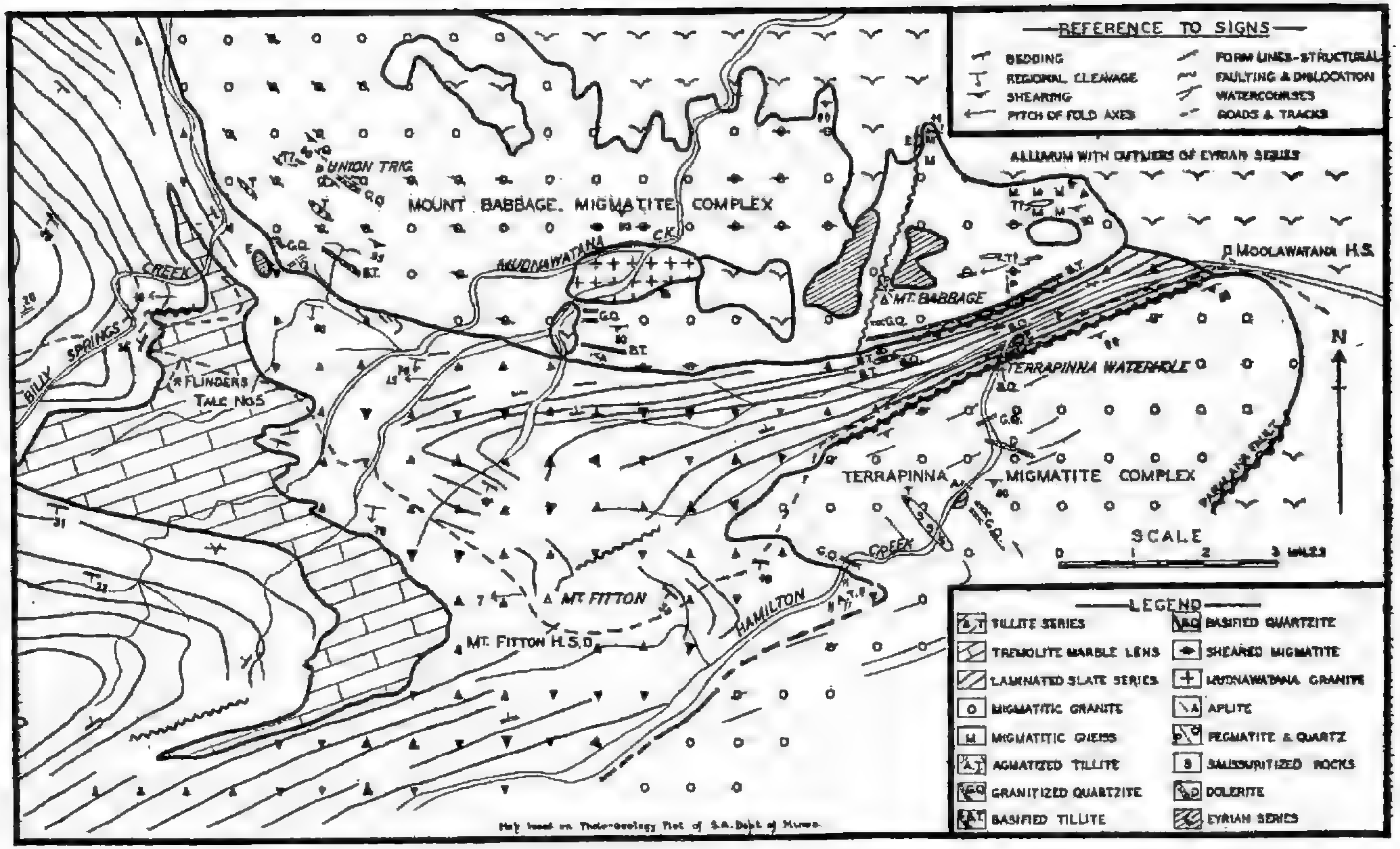

Fig. 2 Reconnaissance geological map; Mount Fitton, South Australia.

1945(b)). Hence the Tillite series is correlated with the Sturt Tillite (as previously suggested) and the Laminated Slate series correlated with the Tapley Hill laminated slates.

(ii) *Eyrian Series*. This series was named and described by Woolnough and David (1926) and David & Browne (1950) tentatively gave its age as Eocene. It consists of gently dipping sandstones and quartzites with underlying shales and sandy shales (Plate X Fig. 1).

(iii) *Post-Tertiary*. David (1932) indicated that the lacustrine beds found near Lake Callabona (*vide* Fig. 1) are of Pleistocene age. Deposition of alluvium has continued to the present day. (*vide* David & Browne 1950, Fig. 150).

(c) Structure

(i) *Early Palaeozoic Movements*. The beds of the Adelaide System are folded with major fold axes directed east-west which is in sympathy with the major fold pattern of the north-eastern Flinders Ranges. There are also some weakly developed, widely spaced cross folds. In the eastern part of the area the folds are tight with steeply dipping or vertical limbs and the fold axes are parallel. These axes pitch from 5° to 15° towards the west, in which direction the folds become more open, the axes fan out and the dips are moderate to small. A prominent east-west regional cleavage developed. The major structural pattern continues through the migmatite complexes which are, in general, located in the anticlines of the tightest folds. The marble lens acted as an incompetent bed and rock flowage took place during folding. Hence the lens has thickened considerably along the axes of major folds. Some of the boundaries are intimately drag-folded and the localization of talc deposits in sheared drag-folded parts of the marble lens has been discussed by Sprigg (1949).

Faulting and shearing took place after the folding and migmatization, but before the intrusion of the magmatic Mudnawatana Granite. Much of the migmatite complexes are traversed by closely spaced east-west shears and faulting took place along the boundaries of the migmatite complexes at the eastern end of the area. In parts there is siliceous crush breccia along the fault zone (Plate X Fig. 1). Movement took place along the Paralana Fault at the same time as in the Mount Painter area where it post-dates the formation of the red migmatitic granite but pre-dates the white magmatic granite.

(ii) *Post Palaeozoic Movements*. Following the early Palaeozoic movements, this part of the crust remained stable until after the deposition of the Eyrian Series when faults developed and isostatic adjustment took place as evidenced by the varying levels at which the Eyrian Series crops out (Plate X Fig. 1). Movement took place mainly along early Palaeozoic fault lines such as the Paralana Fault and along the boundaries of the migmatite complexes.

III. THE COUNTRY ROCKS

(a) The Tillite Series

This series of metamorphosed glacial and fluvioglacial sediments is essentially composed of unsorted, unstratified glacial debris together with banded, stratified slates and siltstones and minor thin quartzite bands. Their extent and distribution and the nature of their outcrop are shown in Fig. 2 and Plate X Fig. 1 respectively.

(i) *The Tillite*. The tillite is usually a dark-grey, metamorphosed, unstratified, gritty mudstone carrying numerous erratics of various shapes and sizes which are promiscuously distributed throughout a fine-grained matrix. Stratification is sometimes shown and the tillite may pass into a banded slate. A

great variety of lithological types are found as erratics, the most common being fine-grained quartzite and granite. The proportion of erratics to rock flour matrix varies considerably from place to place as does the proportion of each lithological type of erratic, but the erratics are always subordinate in amount. The matrix shows that metamorphism reached the biotite grade.

Variations in texture, grain size and angularity of the fragments are infinite, but throughout the area of the country rocks the matrix is always semipelitic being composed essentially of quartz and biotite together with some dolomite and minor amounts of felspar. The chemical composition of the matrix is comparable to that of subgreywacke or greywacke (Table 1).

TABLE I

SiO_2	70·25	H_2O- (110° C)	0·05
TiO_2	0·62	CO_2	1·57
Al_2O_3	10·78	P_2O_5	0·13
Fe_2O_3	1·35	BaO	0·05
FeO	3·54	ZrO_2	0·04
MnO	0·05	S	0·22
MgO	3·66		
CaO	3·43		100·16
Na_2O	1·17	Less O for S	0·09
K_2O	2·77		
H_2O+	0·48		100·07

Average of three analyses of the matrix of the tillite, Mount Fitton (*vide* Bowes 1953, Table I).

Classification on mineralogical composition indicates that the matrix varies from psammitic subgreywacke to pelitic subgreywacke (*vide* Pettijohn 1949, p. 227) but has features which are distinctive of glacial debris. The tillite matrix differs from subgreywacke and greywacke in that K_2O is greatly in excess of Na_2O. This reflects the abundance of biotite and the paucity of felspar. Also MgO is in excess of CaO due to the carbonate fraction being dolomitic.

Detailed petrographic descriptions of the tillite together with an account of its chemical composition and metamorphism and a comparison with Sturt Tillite from other parts of South Australia have been published (Bowes, 1953).

(ii) *The Interbedded Slates and Siltstones.* The rocks of this group are usually semipelitic being composed essentially of a recrystallized mosaic of quartz and biotite and showing variations in composition similar to those shown by the tillite. Some of the rocks contain a variable percentage of carbonate, which, during metamorphism, was the starting point for the formation of actinolitic hornblende. Banded and laminated rocks make up the major part of the group and the stratification of these was used greatly in mapping the structure of the Tillite series. Some contain a few sparsely distributed erratics and transitions from these rocks to true tillite with a structureless matrix are seen.

Some of the country rock relics in the migmatites near Terrapinna are of this group. They are now highly sheared. The more pelitic rocks (9322-3) are composed of recrystallized quartz grains which vary in size from 0·5

mm. to 0·05 mm. together with flakes of brown biotite oriented parallel to the shear planes. Some sericitic mica and calcite are also present. The more psammitic rocks suffered severely during the dislocation metamorphism (9324-5). All the recrystallized quartz shows cracking and strain shadows and sericitic mica is aligned parallel to the planes of shearing. Some biotite, (showing breakdown to chlorite), calcite, tourmaline and magnetite are present.

Quartz amphibole rocks make up part of the series and are representative of siliceous types containing more than the usual amount of carbonate. They are banded greyish-green, dense, compact rocks, the banding being due to variations in grain size and in the proportion of amphibole present (9326). Quartz, the most abundant mineral, is present as angular to subangular fragments which vary from 0·2 mm. to 0·02 mm. The ratio of coarser-grained to finer-grained fragments varies from band to band. Actinolitic hornblende is present as light-green crystals, some of which show sieve texture (the inclusions being the quartz of the matrix), but most are well-formed prismatic crystals which are often radially arranged. Biotite and calcite are absent, but the presence of zircons surrounded by pleochroic haloes and the growth of amphibole at the expense of biotite in other rocks in this area suggest that the reaction of calcite and biotite produced the actinolitic hornblende. Sphene and ilmenite are accessory.

Some of the banded rocks are made up of alternate bands of quartz and biotite and coarser-grained quartz and amphibole (9327). The bands are not always continuous and sometimes the band boundaries are indefinite because of recrystallization and mineral reconstitution. The finer-grained quartz biotite bands are similar to the fine-grained base of the tillites, being composed of a few angular fragments of quartz and microcline (0·5 mm.), together with recrystallized quartz grains (0·04 mm.) and small flakes of biotite oriented parallel to the banding. The amphibole-rich bands are mainly formed of poeciloblastic masses of light-green actinolitic hornblende, up to 1 mm. in length, which show sieve texture, the inclusions being small recrystallized quartz individuals. Some of the amphibole pushed aside biotite flakes during its development. Sphene, apatite, ilmenite and zircon are accessory. It would appear that the banded mineral assemblage is due to variations in the percentage of the carbonate fraction, some bands being similar to the semipelitic slates and siltstones and other bands similar to the quartz amphibole rocks.

The amount of felspar present in the rocks of this group is very small; most of it is potash felspar. Basic plagioclase has not been recognized and the amount of black iron ore is similar to that found in the tillites. Actinolitic hornblende is relatively abundant in some, but the majority of the rocks are composed of quartz and biotite.

(iii) *The Interbedded Quartzites.* The rocks of this group are mainly white, fine-grained and glassy. They consist almost entirely of recrystallized quartz individuals with sutured interlocking borders, and no relics of their original detrital nature remain except for some accessory minerals. The average grain size is usually between 0·5 mm. and 1 mm. Details of the nature and composition of these rocks have been published (Bowes 1952).

(b) The Tremolite Marble Lens

The tremolite marble (9328) is composed of anhedral crystals of dolomite (average grain size 0·25 mm.) together with long thin blades of tremolite up to 3 inches in length. The tremolite is colourless with $Z \wedge C = 17°$ and D.R. is 0·025. A micrometric analysis showed the rock to be composed of 86% carbonate and 14% tremolite. The chemical composition of the rock has been calculated (Table 2) using the formula $(OH)_2Ca_2Mg_5Si_8O_{22}$ for tremolite.

TABLE 2

A		B			
SiO_2	8·3	SiO_2	59·06	Na_2O	Nil
CaO	29·0	Al_2O_3	1·81	K_2O	Nil
MgO	21·3	Fe_2O_3	0·16	H_2O+	5·17
CO_2	41·0	FeO	0·45	H_2O- (100° C)	0·10
H_2O	0·3	MgO	33·12	TiO_2	0·21
		CaO	Nil	P_2O_5	0·08
Total	99·9			Total	100·16

A. Calculated composition (from mode) of tremolite marble (9328). Two miles south-west of Union Trig.

B. Best quality off-white talc. Flinders Talc No. 5 Deposit. Analyst, T. W. Dalwood (Stillwell and Edwards 1951).

The production of tremolite by metamorphism of a siliceous dolomite represents a low grade of metamorphism and did not require a great elevation of temperature (Bowen 1940). This is consistent with the attainment of the biotite grade of metamorphism in the surrounding tillites and slates.

(c) THE LAMINATED SLATE SERIES

This group of rocks is made up of laminated slates, siliceous slates and metamorphosed siltstones together with minor white, buff and blue marbles and minor tillite bands in the lower horizons. All have been recrystallized and reached the biotite grade of metamorphism but none have been migmatized. There has been a little lead-zinc mineralization in a few localized areas and some of the rocks have been altered by contact metamorphism.

The laminated slates and siltstones (9329-30) which make up the major part of this series show well developed banding. This may, in parts, reflect seasonal changes. The features of these rocks are similar to the features of the corresponding rocks of the Tillite series. Siliceous slates and siltstones, which do not break along any direction are a distinctive part of the series. They are dark-grey and composed essentially of quartz and biotite.

In parts members of this series show decussate texture and are hornfelses. Such a rock (9331) forms the matrix of the lead-zinc mineralized zone of the Billy Springs Mine, half a mile west of Flinders Talc No. 5. It is essensially composed of quartz and randomly oriented flakes of brown biotite and larger flakes of muscovite. The grain size of the quartz varies from 0·02 mm. to 0·05 mm. Dolomite, ilmenite, zircon, and sphene are accessory. These hornfelses are considered to be within the metamorphic aureole of a concealed extension of the Mudnawatana Granite (*vide* p. 101).

IV COUNTRY ROCK—MIGMATITE TRANSFORMATIONS

A detailed investigation of the gradations from tillite to granite and gneiss described by Woodward (1885) has shown that these transformations involved migration of material into the country rock and migration of other material out of it. The resultant rock types are "mixed rocks" and hence are called "migmatites" (*vide* Read 1944, p. 63). Large masses of country rock were transformed into migmatites. Tillites, slates, siltstones, and quartzites were all altered by granitization and show gradations to migmatitic augen granite. Basification also altered some of the tillites, slates, and siltstones to labradorite, amphibole, ilmenite rocks, and the quartzites to amphibole, clinozoisite, quartz rocks.

(a) The Transformation of Tillite

(i) *By Granitization.* The transformation of tillite into migmatitic augen granite (Table 3), which sometimes contains relic tillite erratics, can be

Table 3

SiO_2	72·34	H_2O+	0·54
TiO_2	0·30	H_2O–(110° C.)	0·09
Al_2O_3	13·12	P_2O_5	0·08
Fe_2O_3	1·37	BaO	0·02
FeO	1·90	ZrO_2	0·20
MnO	Tr	S	abs
MgO	0·41	Cr_2O_3	abs
CaO	1·35		
Na_2O	2·73	Total	99·93
K_2O	5·48	S.G.	2·60

Migmatitic augen granite (9299). Five miles north-west of Mount Fitton. Analyst, D. R. Bowes.

demonstrated in many places along the boundaries of the migmatite complexes. Subsequent shearing movements have destroyed the clear evidence of transformation in parts, but in other areas the rocks are unsheared and the transition can be clearly seen. Many unaltered and little altered erratics remain in the granitic migmatites in the border zones of the complexes. Granitization involved an increase in K and Na and, in most cases Si, and a decrease in Fe, Mg, Ca, Ti, P, and Mn. In general each part of the rock was altered to the same extent as the adjacent part but in some of the rocks permeation took place preferentially and the process was one of agmatization.

(ii) *By Basification.* Rocks which show many of the characteristic features of tillite, but which are epidiorite-like and are composed of labradorite, actinolitic hornblende and ilmenite with a relic quartz mosaic, are found in the Mount Babbage Migmatite Complex and also in the Tillite series. The available evidence suggests that the unusual composition of these epidiorite-like rocks is not an original sedimentary composition but is due to the transformation of tillite by basification : Fe, Ca, Mg, Ti, Mn, and Cr were introduced and Si and K were expelled.

Detailed petrographic descriptions, analyses and microphotographs illustrating the stages of alteration of tillite by granitization to migmatitic augen granite both by direct replacement and by agmatization and its alteration by basification to epidiorite-like rocks is published separately (Bowes 1953).

(b) The Transformation of Slates and Siltstones.

(i) *By Granitization.* The granitization of the interbedded, banded slates and siltstones, which contain no erratics, and the resultant production of migmatitic granite is illustrated at many points along the boundaries of the migmatite complexes (especially along the southern boundary of the Mount Babbage Migmatite Complex) and also around the edges of the country rock relics within the complexes. Fine-grained rocks rich in potash felspar were produced at an early stage and transitions from country rock to a light-coloured, fine-grained quartz, microcline, biotite, migmatite (9332) can be seen. Some of the associated rocks show the development of medium-grained quartz individuals with ragged edges in a finer-grained quartz microcline mosaic (9333). These fine-grained migmatitic granites pass quickly into coarse migmatitic augen granite similar to that produced by the granitization of tillite although in parts the felspars are rectangular and lath-like (9334). The

chemical changes involved in these transformations are similar to those in the transformation of tillite to migmatitic augen granite.

(ii) *By Basification.* Dark greenish coloured rocks similar in appearance and composition to those considered to be formed by the basification of tillite are found in a few places in the Mount Babbage Migmatite Complex. Although it is not possible to trace a complete sequence of transformations from unaltered country rock to a patchy labradorite amphibole rock, these rocks show similar textures, mineralogical associations and composition to those shown by the basified tillites. On these grounds, and because of the absence of labradorite, the paucity of ilmenite and the smaller amount of amphibole in the slates and siltstones, these epidiorite-like rocks are considered to be altered sediments, which originally contained no erratics.

In the early stages of transformation the rocks are fine-grained (9335-6) and made up of small prismatic and larger poeciloblastic crystals of actinolitic hornblende and small calcic plagioclase laths (AB_{42}). Both these minerals grew at the expense of a fine-grained quartzose mosaic, relics of which remain in both amphibole and plagioclase. Golden-brown biotite, apparently replacing amphibole, is seen as clusters. At an advanced stage of transformation, patchy green and white rocks were formed (9337-8) in which the grain size is considerably greater. Skeletal patterns of ilmenite and large crystals of apatite are a notable feature. The mineralogical variations shown by these rocks are similar to those described in connection with the basification of the tillite.

(c) The Transformation of Quartzite

(i) *By Granitization.* The quartzites withstand transformation by migmatization to a much greater extent than the associated slates, siltstones and tillite matrixes and because of this it is possible to trace bands, which were originally quartzite, in the migmatite complexes, when all the associated rocks have been transformed beyond recognition. It is in these bands that the transformation of quartzite by granitization can be seen. The final product is a migmatitic augen granite indistinguishable from that produced by the granitization of the tillites, slates and siltstones (Table 3). This involved a considerable decrease in quartz and an increase in potash felspar, biotite, and acid plagioclase; Si decreased and Ti, Al, Fe, Mg, Ca, Na, K, and H increased, K. Al, and Na particularly.

(ii) *By Basification.* Quartzites which contain clinozoisite and actinolitic hornblende in variable amounts are found as small irregular patches amongst the Tillite series. The presence and relative abundance of this suite of minerals bears no obvious relation to any bed or sedimentary feature and it would appear as if any concentration of these minerals indicates the introduction of cafemic constituents into the quartzite in localized patches. Basification involved a decrease in the amount of quartz and an increase in actinolitic hornblende, clinozoisite, sphene and ilmenite; Si and K decreased and Ti, Al, Fe, Mg, Ca, and H increased.

Detailed petrographic descriptions, micro-drawings and discussion of the stages of the alteration of quartzite by granitization and basification have been published. (Bowes 1952).

(d) Interrelation of Transforming Processes

The constituents driven out of the tillites, slates and siltstones during their granitization were those introduced into these rocks during their basification and *vice versa*. The processes of granitization and basification were thus complementary in the Mount Fitton area. In the case of the quartzites both granitization and basification involved a considerable desilication and

addition of bases. Silica was thus provided for the granitization of the associated tillites, slates and siltstones and the bases expelled from these rocks were, in part, fixed in the quartzites. Hence the presence of quartzites in the Tillite series prevented the extensive development of basic, epidiorite-like rocks during migmatization and the alterations by granitization and basification of the tillites, slates, siltstones, and quartzites are all part of a regional migmatization and are intimately connected.

V. THE MIGMATITE COMPLEXES

Large masses of country rock were transformed by migmatization in the Mount Fitton area and these altered rocks crop out as two large complexes named by Sprigg (1951) the Mount Babbage and Terrapinna Granite Complexes. As these rocks are migmatitic in character and genesis and are not entirely granitic, it is considered best to refer to them as the Mount Babbage and Terrapinna Migmatite Complexes (Fig. 2). They are situated at the northern and eastern parts of the area where the folds are tightest and in each case they appear to be localized in the core of an anticline. Ghost sedimentary structures may be recognised in them and these have the same major pattern as the country rock structures. No migmatites are exposed at the present level of erosion in the central and western parts of the region where the folds are more open.

The rocks found within the boundaries of the migmatite complexes can be divided into the following groups: (i) migmatitic granites, including the marginal granitized country rock—this is the main group in each complex; (ii) sheared migmatitic granites; (iii) migmatitic schists and gneisses; (iv) sheared migmatitic schists and gneisses; (v) epidiorite-like migmatites including marginal basified rocks; (vi) country rock relics; (vii) Mudnawatana Granite (which is considered to be mobilized migmatite) and its associated aplites, pegmatites, quartz veins and chloritized, saussuritized rocks. Groups (ii) and (iv) are the sheared equivalents of (i) and (iii) and are described in the following section; group (vi) has been described and group (vii) will be described later.

(a) The Terrapinna Migmatite Complex

This complex covers an area of more than 20 square miles in the area mapped and consists of an outer rim of sheared migmatitic granite (Plate XI Fig. 1) with a main central core of migmatitic augen granite which weathers giving tor structure (Plate X, Fig. 2). Transitions from country rock into migmatitic granite are shown in some places along the boundaries, agmatized tillite is seen in the banks of the Hamilton Creek on its southern boundary and some country rock relics remain. Many of the rocks show evidence of post-migmatization shearing and aplites, dolerite and chloritized and saussuritized rocks are also found. An extension of the complex is seen in the southern part of the area and continues in the direction of the Freeling Heights and Mount Painter.

Migmatitic augen granites make up the main part of the complex. Large ovoids of microcline microperthite, up to 5 x 3 cm. in cross section are associated with irregular masses of quartz, which often have a bluish opalescent tint and are up to 3 x 3 cm., and clots of brown biotite (9339). Quartz is often included in the potash felspar and in parts fine worm-like intergrowths of potash felspar are seen in the quartz. Some of these rocks also show a finer-grained sutured quartz felspar mosaic. The relative amounts of these two minerals vary from place to place and in some parts the large felspars merge into a mosaic of finer-grained felspar. Myrmekitic intergrowths

are sometimes seen (9340). The amount of acid plagioclase (Ab_{78}-Ab_{70}) varies. Some rocks contain equal amounts of potash felspar and plagioclase (9341) while in a few acid plagioclase (Ab_{68}) is the dominant felspar present and forms the augen (9342). These rocks are *migmatitic adamellites and granodiorites* respectively. In all these rocks biotite is the only mafic mineral present. It is seen as nests and irregular patches of flakes and contains inclusions of quartz, zircon, apatite and iron ore. Some of the biotite shows a breakdown to chlorite and muscovite is present in variable amounts.

Although the migmatites are generally a coarse augen type, some *even-grained migmatitic granites* of medium to coarse grain size are present. These rocks are essentially made up of quartz, microcline, microcline microperthite and biotite as well as some muscovite (9343-4). Finer-grained granitic migmatites, some containing large poeciloblasts of potash felspar represent original quartzite and quartz-rich bands (Bowes 1952).

The similarity in both macroscopic and microscopic characters and appearance between these migmatitic augen granites and the "augen granite" of Herma Ness, Unst, Shetland Islands (Fernando 1941) is worthy of note.

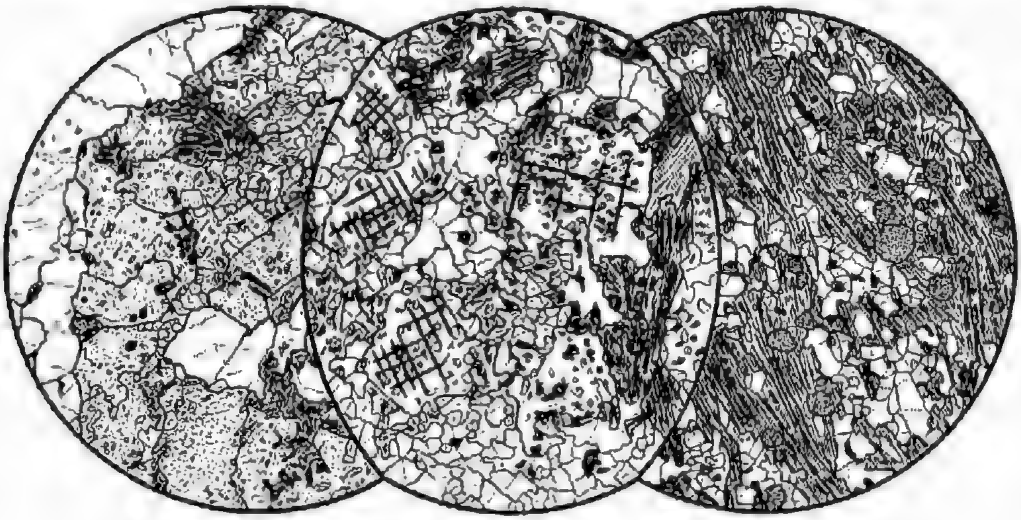

Fig. 3 Migmatitic gneisses, two miles north of Mount Babbage.

(a) Cordierite (showing sieve texture with inclusions of quartz), sillimanite, quartz, tourmaline gneiss (9347). X 16.

(b) Microcline, quartz, biotite, muscovite, garnet gneiss (9349). Zircons, surrounded by haloes, and apatite laths are included in the biotite. X 16.

(c) Biotite, quartz, garnet gneiss (9351). X 16.

(b) The Mount Babbage Migmatite Complex

This complex covers approximately 40 square miles in the area mapped. Only its southern boundary with the country rocks is shown as the migmatites are unconformably overlain by alluvium to the north. The rocks of this complex have suffered more general shearing than those of the other complex and sheared migmatitic granite is as common as its un-sheared parent. Small areas of epidiorite-like migmatite are seen, migmatitic gneisses and schists crop out in two areas in the northern parts and country rock relics remain, especially near the southern boundary. The Mudnawatana Granite crops out in the depressed central area and aplites, pegmatites and quartz veins also occur, especially in the eastern part.

Migmatitic augen granites, together with their sheared equivalents, make up the main mass of this complex. They are similar to the rocks found in the Terrapinna Migmatite Complex, being composed of large felspar augen (usually potash felspar), irregular masses of quartz which sometimes has a bluish opalescent tint and nests of biotite flakes (9299) (Plate X Figs 3 & 4). The composition of the plagioclase felspar varies from Ab_{85} (9345) toAb_{68} (9346) although the general composition is Ab_{70}. In some of the more felspathic rocks biotite is scarce. *Even-grained migmatitic granites* with medium-coarse grain size are also present and these often represent granitized quartzites or siliceous bands.

Migmatitic gneisses and schists crop out *north of Mount Babbage*. Quartz-rich rocks, in which cordierite developed at the expense of the quartz mosaic, relics of which remain giving sieve texture, are seen. Sillimanite is associated with the cordierite and tourmaline, muscovite, clinozoisite, apatite, magnetite, sphene and zircon are accessory (9347-Fig. 3a). Patchy pink rocks containing garnet as well as labradorite (Ab_{42}), green amphibole, cordierite, clinozoisite and sphene are also present (9348). The cordierite again shows sieve texture and contains numerous relics of the original quartz mosaic. The presence of sillimanite and cordierite in these rocks is not necessarily indicative of a high grade of recrystallization metamorphism as the formation of these minerals by metasomatism has been described (Watson 1948; Bowes 1948).

Granitic gneisses, essentially composed of quartz, felspar and biotite also crop out. Porphyroblasts of both microcline and oligoclase developed; some contain numerous micaceous inclusions while others have abundant quartz inclusions and show sieve texture. Biotite, together with minor amounts of muscovite developed and clusters of garnets formed (9349-Fig. 3b). In some of the rocks little or no felspar is present and quartz, biotite and garnet are the essential constituents (9350).

Biotite-rich rocks were also developed. Biotite, quartz and garnet together with accessory muscovite, zircon, apatite, rutile and tourmaline constitute some of the rocks (9351-2—Fig. 3c) while in others plagioclase (Ab_{65}) developed but not garnet (9353). All show distinct foliation due to the parallel alignment of the biotite. Permeation of quartz felspar stringers along the foliation is seen in some of these rocks.

Migmatitic gneisses also crop out *north-east of Mount Babbage*. Permeated psammitic rocks are now quartz, felspar, biotite rocks with quartz by far the most abundant mineral (9354). Both microcline and plagioclase (Ab_{70}) grew at the expense of the quartz mosaic, relics of which are dotted throughout these minerals giving them sieve texture in parts. The biotite flakes show parallel alignment and muscovite, garnet and magnetite are accessory. Permeated semipelitic rocks are seen as vaguely banded gneisses made up of orange-pink streaks of quartz, microcline and acid plagioclase (Ab_{70}) with some garnet and parallel bands of biotite with some muscovite (9355). Other gneisses are coarse-grained and granitic in composition (9356) while others of the same composition are fine-grained or composed of alternate coarse and fine-grained bands. A few large poeciloblasts of potash felspar containing numerous quartz inclusions have developed in medium-coarse grained migmatitic granitic gneisses (9357-8) which pass out into the migmatitic granites and migmatitic augen granites of the Mount Babbage Migmatite Complex.

(c) Homogenization

The homogeneous nature of the migmatitic augen granite (Plate X Figs. 2, 3, 4, and Table 3), which makes up the major part of the migmatite complexes, stands out in contrast to the varied nature of the country rocks—heterogeneous tillite, banded slate and siltstone, and quartzite—which were

altered by migmatization to this granite. The granitization of the tillites and slates involved, in each case, the addition of K and Na and the removal of Fe, Mg, Ca, and Ti, and in many cases the addition of Si and removal of Al. During the granitization of the quartzites K and Na were added as well as Fe, Mg, Ca, Ti, and Al, and Si was removed. Hence, apart from a percentage of the alkalies which had to be introduced into the area, those materials driven out of the semipelitic rocks during granitization were those introduced into the psammitic rocks and *vice versa*. This reconstitution of the diverse types of country rock, together with some addition of alkalies and perhaps silica, produced the migmatitic augen granite which is essentially homogeneous throughout the complexes. Small variations do occur, but in many cases these represent stages of development of the migmatitic granite.

Associated with and related to the homogenization was extreme metamorphic differentation. The cafemic constituents which were driven out of the semipelitic rocks during their transformation to migmatitic granite and which were in excess of that needed to granitize the psammitic rocks were fixed in the now basified rocks. The localization of some of these basified patches may have been due to an originally more calcareous rock type in the particular area.

VI. POST-MIGMATIZATION MOVEMENTS AND DISLOCATION METAMORPHISM

Many of the rocks of the Mount Fitton area have been sheared and altered by dislocation metamorphism. Along localized fault planes and shear belts the effects of these movements were extreme, but for the most part the sheared rocks show slighter crushing and granulation accompanied occasionally by mineralogical changes. Both country rocks and migmatite complexes have been affected in this manner although shearing in the migmatites was generally more intense.

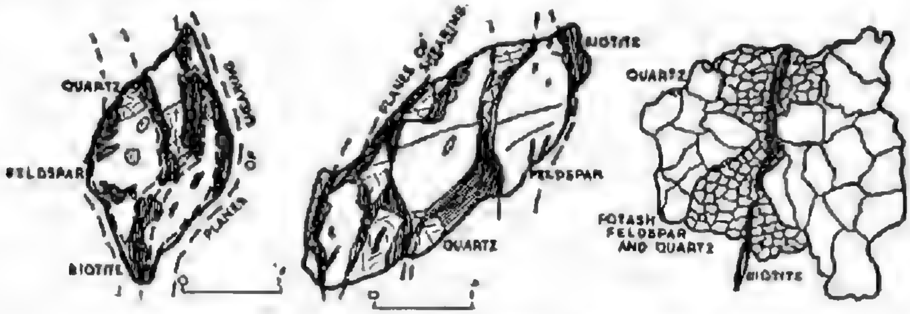

Fig. 4 Sheared migmatitic granites.

(a) Composite quartz, felspar augen together with biotite aligned along shear planes (9362).

(b) Sheared migmatitic augen granite (9373).

(c) Irregular lobes of quartz showing a sutured mosaic together with a fine-grained, granulated quartz and felspar mosaic and biotite aligned along shear planes (9377). X 5.

(a) Dislocation Metamorphism in Shear Zones

In the shear zones in which the movements were concentrated (*vide* Fig. 2) dislocation metamorphism was intense, crushed and brecciated rocks being the result. The homogeneous quartzites were broken and the fragments were cemented by siliceous or ferruginous material. In the felspathized quartzites the quartz was drawn out into lenses and streaks around which are wound

lines of biotite flakes (9359). Some of the biotite was retrograded to chlorite and the potash felspars are seen to be greatly sericitized. In the tillites the larger quartz individuals have shattered and ragged edges and these and the more quartzose areas of the matrix form small augen around which wind closely-spaced foliation planes formed by the parallel orientation of green-brown biotite and muscovite (9360). The more argillaceous rocks are now phyllitic and are composed of large chlorite flakes and small biotite flakes together with small strained and cracked quartz individuals with granulated edges. (9361).

Migmatitic augen granites were altered to schistose granulated rocks composed of cracked and granulated quartz masses around which twist elongated, sheared masses of biotite and sericite. Some of the augen are composite patches of quartz and felspar (9362-Fig. 4a) while relic tillite erratics also form augen (9363). Between some of the augen there is a fine-grained granulated groundmass made up of strained quartz, broken sericitized felspar individuals together with clusters of biotite flakes. Accessory zircon, black iron ore, apatite and garnet are also seen.

(b) Dislocation Metamorphism of the Country Rocks

Outside the shear zones the country rocks show few effects of this dislocation metamorphism. There is an E-W regional shearing in parts which usually coincides with the axial plane cleavage. In the minor folds near the boundaries of the Tremolite Marble lens some of the marble is intensely sheared giving rise to a cleaved schistose dolomite (9364-6). This shearing, which is very localized, took place during the folding and provided the structural traps for the metasomatic fluids which altered the marble to talc in many places.

Much of the quartz of the tillites and quartzites shows strain shadows, undulose extinction and in some parts cracking, but in general there has been no granulation. There have been no mineralogical breakdowns due to dislocation metamorphism.

The migmatite complexes suffered more than the country rocks as a result of this episode, and the country rock relics in the migmatite complexes have been altered more than the country rocks themselves. Quartz-rich rocks were altered to quartz chlorite schists (9367) and slates were altered to green phyllitic schists and quartz, biotite, sericite schists in which the micas are oriented in the shear planes and the quartz has been cracked and, in parts, granulated.

(c) Dislocation Metamorphism of the Migmatite Complexes

The effects of dislocation metamorphism are considerable in parts. Sheared augen gneisses are common as is mortar structure. Only the peripheral zones of the Terrapinna Migmatite Complex were affected (Plate XI Fig. 1), but much of the Mount Babbage Migmatite Complex was greatly sheared.

Effect on felspathized quartzites. Quartzose crush rocks in which large cracked and broken knobs of quartz and granulated, partly sericitized potash felspars are set in a fine-grained granulated quartz-felspar groundmass were produced. Both sericite and biotite are scattered throughout the groundmass as well as being concentrated in patches and drawn out streaks along shear planes (9368-9).

Effect on even-grained migmatitic granites. The dislocation metamorphism produced similar results in these rocks. The quartzes show undulose extinction, cracking and granulation and the felspars have also been ground and broken, especially on the edges, and sericitized in parts. Streaks and strings

of both biotite and sericitic muscovite wind around eyes of quartz and felspar and there is a granulated quartz-felspar mosaic in parts (9370-2).

Effect on coarse migmatitic augen granites. These rocks have been broken down to granitic augen gneisses. The large felspar augen remain (9373-Fig. 4b) and although cracked with many parts broken away, they are still the dominating feature in these rocks. Quartz, medium-grained felspar and biotite make up a granulated matrix between the augen. Microcline or microcline perthite individuals make up the augen in most of the rocks (9374), although acid plagioclase forms the augen in some rocks (9375-6), and in some there are augen of both potash and plagioclase felspar. All these large felspars are granulated around the edges, show fracturing and often have these fractures filled with fine-grained quartz and felspar. Lobes and irregular lenses of clear quartz crystals are common. These all show strain shadows, undulose extinction and cracking to give a sutured quartz mosaic (9377-Fig. 4c) and in parts are surrounded by a fine-grained granulated felspar-quartz mosaic. Long strings of biotite are usually present along shear planes; some of this biotite has been retrograded to chlorite. Sericite is common in parts; sometimes it shows a habit similar to biotite although much of it is altered potash felspar. Magnetite, apatite and zircon are common accessories and sphene is sometimes present. In parts the plagioclase felspars are saussuritized, giving a fine-grained mass of zoisite and albite.

The distinctive character of these granitic augen gneisses makes it possible to correlate xenoliths in the Mudnawatana Granite with rocks from the migmatite complex (9378).

Effect on migmatitic gneisses. Many of the migmatitic gneisses on the northern boundary of the Mount Babbage Migmatite Complex, two miles north of Mount Babbage, were little affected during this episode. In some of the rocks the quartz shows some straining and biotite shows some alignment in others, but this may have no relation to the shearing.

The migmatitic gneisses cropping out in the north-eastern part of the Mount Babbage Migmatite Complex have been much sheared in parts. Quartzes have been strained and cracked and the banded nature of the rocks accentuated by shearing.

(d) Significance of the Episode

This period of shearing indicates that rocks which had been migmatized became more rigid and in such a state that they could be affected by dislocation metamorphism. It seems likely that these rocks were migmatized in the deeper levels of the crust and later elevated to the higher levels. In this instance the period represents a stage where geosynclinal sediments which had been depressed, folded and metamorphosed were later raised to levels of the crust where the rocks were hard and brittle and both cracking and granulation were possible. The retreat of the migmatite front may have been another factor leading to the rigidity of the rocks.

The change in depth of burial, or in position relative to the zone of migmatization, must represent a considerable period of time between metamorphism and migmatization and the shearing movements. Migmatization may still have been active during the period of shearing but at a much greater depth.

VII INTRUSION OF THE MUDNAWATANA GRANITE

The next major event in the tectonic history of the area was the intrusion of a white, non-stressed granite which crops out in the central part of the Mount Babbage Migmatite Complex. As the Mudnawatana Creek flows across the area of its outcrop and the intrusive relations of the granite are well shown in the bed and banks of the creek, the granite has been named the Mudnawatana Granite (Plate XI Fig. 2). Immediately following its intrusion and associated with its crystallization history was a period of injection of aplite dykes, pegmatite and quartz veins and of metasomatic activity (Plate XI Fig. 4).

(a) The Mudnawatana Granite

(i) *Criteria for Intrusion.* (i) A sharp transgressive contact is shown between the granite and the associated migmatites and sheared migmatites. In parts this contact cuts directly across the foliation of the sheared migmatites. (ii) The injection of tongues and stringers of granite into the surrounding rocks is a common contact phenomenon. Preference was shown for injection along the foliation planes of the sheared migmatite. (iii) Disoriented xenoliths of sheared migmatite are seen in the well-exposed rock faces in the bed of the Mudnawatana Creek at the northern contact, suggesting intrusion by piecemeal stoping of blocks at the roof of the chamber. (iv) Textural evidence alone is not conclusive but the allotriomorphic-hypidiomorphic texture shown by the granite is usually considered as of magmatic origin. A comparison of this texture (Plate XI Fig. 3) with that of the texture of the migmatitic granite (Plate X Fig. 4) suggests a significant difference in their genesis. (v) Zoning of plagioclase felspars is shown in the granite (Plate IX Fig. 3) and this zoning corresponds with that of the ideal plagioclase cooling curve given by Bowen (1928). None of the migmatites contain zoned plagioclase.

(ii) *Petrography.* The granite (9379-80) is practically constant in nature and composition being medium-grained, equigranular with average grain size 1·5 mm. showing allotriomorphic-hypidiomorphic texture and consisting essentially of acid plagioclase, quartz, microcline and biotite (Plate XI Fig. 3). *Acid plagioclase* is the most abundant mineral, being present as large laths showing concentric zoning with the composition of the outside zones Ab_{74}. Smaller subhedral laths of the same composition are also present. The cores of the zoned crystals are more basic and are often altered to a felted mass of calcite and zoisite. *Quartz* is nearly as abundant as acid plagioclase being present as clear anhedral masses. *Potash felspar* is also of major importance, but is only half as abundant as acid plagioclase or quartz. It is mainly represented by anhedral microcline although a little microperthite and micropegmatite are present. *Biotite* is the only mafic mineral of importance. Unoriented flakes, showing pleochroism x = light golden, y = golden brown, z = dark brown are scattered throughout and often include *zircons* surrounded by pleochroic haloes. Some of the biotite has been altered to light-greenish *chlorite* with the liberation of black iron ore. *Muscovite* is found associated with the biotite; it also occurs as small flakes in the cores of the zoned plagioclase crystals.

Magnetite is accessory. A micrometric analysis (Table 4) indicates that the rock should be classified as an adamellite on the border of this group close to granodiorite.

(iii) *Space Relations and Genesis.* All field evidence points to this granite being a high-level intrusion with only the topmost part of the mass visible at the present level of erosion. Round knob-shaped outcrops are cupola-like in

appearance and the presence of isolated masses of migmatite within the area of granite outcrop suggests that they are remnants of the roof of the intrusion. The presence of small xenoliths in the granite, near its contact, is indicative of high-level stoping at the roof of the chamber, and their lack of metasomatic alteration, even though they were immersed in the magma, shows that the period of time between the stoping and immersion of the xenoliths and the final crystallization of the magma was comparatively short.

TABLE 4

Quartz	35·4	Muscovite	2·0
Plagioclase (Ab_{91})	37·5	Zoisite, Calcite	0·8
Microcline	16·6	Chlorite, Iron ore, Zircon	0·4
Perthite	1·4		
Micropegmatite	0·9		
Biotite	5·0		
		Total	100·0

Mode of Mudnawatana Granite (9380), Mount Fitton.

It is only possible to suggest the underground extension of the granite mass. Thick quartz veins are of common occurrence in the area of the Mount Babbage Migmatite Complex and pegmatite veins are common in the eastern part of this complex. These were injected after the post-migmatization shearing movements and are correlated with the last stages of the cooling history of the Mudnawatana Granite. It appears likely that the underground lateral extent of the granite is greater than that of the present exposures of the Mount Babbage Migmatite Complex. Quartz veins were injected into the rocks of the Tillite series and aplite dykes crop out in the central part of the Terrapinna Migmatite Complex. Metasomatic activity associated with the granite is considered to be responsible for the production of talc at numerous points in the Tremolite Marble lens and also the chloritization and saussuritization of some of the rocks of the Terrapinna Migmatite Complex. The presence of hornfels in the Laminated Slate series west of Flinders Talc No. 5 workings (*vide* Dickinson 1949) and at the Billy Springs Mine is also indicative of a further underground extension of the granite. Hence it would appear that the granite underlies much of the Mount Fitton area, cropping out in the central part of the Mount Babbage Migmatite Complex and being close to the surface in the central part of the Terrapinna Migmatite Complex and just west of Flinders Talc No. 5 workings.

The intrusion of the Mudnawatana Granite after the post-migmatization shearing is indicative of the lapse of a considerable period of time between the formation of the migmatitic granite and the intrusion of this magmatic granite. This suggests that the magmatic granite was not responsible for the migmatization but that the production of a granite magma was the culmination of the migmatization and was due to the mobilization of part of the crust which had previously been made over by migmatization to a rock having a granitic composition. The post-migmatization shearing movements may be an expression of readjustment following changes of volume and density which took place during the formation of the migmatites and their subsequent mobilization (at lower levels of the crust). The shear planes in the rocks facilitated the diapiric intrusion and piecemeal stoping of the magma.

(b) Aplite Dykes

Dykes of granite aplite are found south of the outcrop of the Mudnawatana Granite and in the banks of the Hamilton Creek, one and a half miles south of Terrapinna Waterhole. The dykes cut both migmatitic granite and sheared migmatitic granite. They often follow the east-west shear direction but in many parts cut across this direction and some of the dykes bifurcate (Plate XI Fig. 4). They show an allotriomorphic texture, have an average grain size of 1 mm., and consist essentially of anhedral crystals of microcline and quartz together with minor amounts of perthite, micropegmatite, brown biotite, acid plagioclase and accessory zircon (9381). In parts little biotite is present, the grain size is greater and some muscovite is seen (9382).

(c) Pegmatitic and Quartz Veins

The occurrence of pegmatite and quartz veins, which show cross-cutting relations to the sheared migmatites, gives evidence of late-stage hydrothermal activity associated with the Mudnawatana Granite. The pegmatites, which are always coarse-grained and composed of quartz, potash felspar and white mica, are found cutting the Mount Babbage Migmatite Complex, especially just east of Mount Babbage. The quartz veins are always massive and made up of white, barren quartz. They are known to cut the country rocks, migmatites and sheared migmatites, and are most commonly found injected into the Mount Babbage Migmatite Complex. In parts the veins are up to six feet in width and may be followed intermittently up to one hundred yards.

The massive form, constancy of width and direction, and cross-cutting relations with the sheared migmatites rule out any possibility of associating these pegmatite and quartz veins with the migmatization.

(d) Metasomatic Activity

As well as the injection of pegmatite and quartz veins, metasomatic activity due to the circulation of hydrous siliceous fluids is associated with the final phase of cooling of the Mudnawatana Granite. The talc lenses and a mass of chloritized and saussuritized country rocks and migmatites in the Terrapinna Migmatite Complex are considered due to the action of these fluids.

(i) *The Formation of Talc.* The petrology of the talc deposits has been discussed by Stillwell & Edwards (1951) who conclude that the "metamorphosed character of the hornfels and the dolomite marble, coupled with the presence of granite in the vicinity, suggests that the talc deposits were formed by a localized metasomatic replacement of the dolomite marble succeeding the contact metamorphism of the area". The present investigations in the surrounding area have confirmed these views, but have indicated that the metasomatic activity was associated with the Mudnawatana Granite.

The chemical changes involved in the transformation of tremolite marble to talc can be seen by a comparison of their respective compositions in Table 2.

(ii) *Chloritization and Saussuritization.* Some rocks of the central part of the Terrapinna Migmatite Complex have been altered by the chloritization of the biotite and saussuritization of the plagioclase felspars. Many show the effects of shearing but the production of the chlorite and saussurite appears to be due to late metasomatic activity of the Mudnawatana Granite in rocks which had been sheared and made accessible to circulating solutions. This is supported by the presence of granite aplite dykes and veins half a mile north of these outcrops, which indicates that the roof of the granite mass is not far below the present level of erosion in this part. The altered rocks are

characteristically much darker than the surrounding rocks due to the dark colour of the felted chlorite and the staining effects of the iron liberated by the change of biotite to chlorite.

Effect on country rock relics. Country rock of uneven grain-size and showing the characteristic features of the matrix of a tillite has suffered chloritization (9383). Angular and subangular fragments of quartz, up to 4 mm. across, are common, there are some sericitized potash felspar fragments and the groundmass of grain size 0·1 to 0·5 mm. consists of a felted interlocking mass of chlorite flakes and recrystallized quartz. Black iron ore is associated with the chlorite and haematite and limonite give rise to localized heavy staining. There has also been introduction of fresh, uncracked crystals of amythestine quartz. The associated slates have been similarly altered (9384).

Effect on granitic migmatites. The saussuritization of the plagioclase and chloritization of the biotite has resulted in the formation of rocks with a peculiar but characteristic spotted appearance. Large orange-pink ovoids (up to 4 x 3 cm. in cross section) of cracked and sheared microcline and smaller knobs of bluish opalescent quartz are set in a dark greenish-black groundmass of saussuritized plagioclase (Ab_{71}), in which a felted intergrowth of zoisite has developed, and chloritized biotite (9385). The chlorite is mainly present as large flakes which are pseudomorphs of biotite, although small brown biotite relics remain. The iron ore liberated during this alteration is abundantly dotted throughout the chlorite flakes and there are haematite stains along some of the cracks in the rocks.

(e) Uralitized Dolerite Dyke

A dolerite dyke which cross-cuts the shear planes in sheared migmatitic granite and has not been affected by the shearing cuts across the Hamilton Creek south of Terrapinna Waterhole. The relation of this dyke to the Mudnawatana Granite cannot be directly observed but it is possible that it has similar relations to the dolerite dykes at Rosetta Head, South Australia, which cut the granite but are cut by pegmatitic and quartz veins (Bowes 1948). Uralitization has altered the dyke and the rock consists essentially of laths of saussuritized basic plagioclase (Ab_{48}) and prismatic crystals of uralitic hornblende showing pleochroism x = light green, y = grass green, z = olive green. Some sub-ophitic texture still remains. Sphene is seen in parts and some of it was formed at the expense of ilmenite, as a rim of sphene surrounds some of the ilmenite crystals. A little brown biotite is also present (9386).

VIII. CORRELATION AND AGE

Numerous occurrences of granites of early Palaezoic age have been described from the southern and south-eastern parts of South Australia. Stressed, syn-tectonic, migmatitic granites from the Palmer district have been described (Rattigan & Wegener 1951) and unstressed, post-tectonic, intrusive, magmatic granites from many areas have been described (Tilley 1919; Browne 1920; Kleeman 1934; Mawson & Parkin 1943; Mawson & Dallwitz 1944; Mawson & Segnit 1945, and others).

Granitic rocks of similar age also crop out in the vicinity of Mount Painter, 20 miles S.S.W. of Mount Fitton (Sprigg 1945 (b)). Two main types have been recognised, a stressed syn-tectonic migmatitic granite and an unstressed, post-tectonic, magmatic granite which intrudes the sediments of the Adelaide System and the migmatitic granite (*vide* Miles 1947, Plate 1). These granites have been referred to as the "red granite" and "white granite"

respectively [2] (Sprigg 1945 (b)). Cupola-like masses of leucocratic granite which intrude Adelaide System sediments also crop out near Umberatana, 15 miles west of Mount Painter (Mawson & Dallwitz 1945).

The presence of both migmatitic and magmatic granites has been demonstrated in the Mount Fitton area. Hence in the Mount Painter area, and in southern and south-eastern South Australia, there were two periods of granite formation during the orogenic cycle which followed the collapse of the geosynclinal area in which the Proterozoic and Cambrian beds were deposited. Firstly there was the syn-tectonic formation of migmatitic granites followed by shearing movements, and secondly, the intrusion of younger post-tectonic unstressed granites. Although considered separately for the sake of convenience and showing definite limits at the present level of erosion, the episodes of migmatization, shearing and granite intrusion should not be thought of as separate episodes. They are intimately connected both in time and place.

It would appear as if the granitic rocks of southern and south-eastern South Australia were formed following the collapse of the eugeosyncline which extended to the east and south-east of the miogeosyncline in which the sediments of the Adelaide System were deposited. On the other hand, the granites of the north-eastern Flinders Ranges represent a migmatized and mobilized section of the beds deposited in the miogeosyncline.

The date of the final phase of the orogeny in the north-eastern Flinders Ranges has been fixed by an age determination of 400±50 million years on a samarskite (Kleeman 1946) which occurs in late-phase off-shoots of the Freeling Granite which are found in shatter zones in the migmatitic granite of the Mount Painter Complex. This gives the age as mid-Ordovician (Holmes 1946).

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I wish to record my thanks to the Royal Commissioners for the Exhibition of 1851 for the award of a Science Research Scholarship which enabled me to carry out this research and to Professor H. H. Read for his guidance and helpful criticism. Mr. R. C. Sprigg brought the problem to my notice and made available data he had collected; Mr. S. B. Dickinson, Director of South Australian Department of Mines, provided facilities for field work; Professor Sir Douglas Mawson made available a University of Adelaide research grant which made a re-examination of the area possible; Mr. A. W. Kleeman kindly read the manuscript, and Messrs. J. Barlow, I. V. Hansen, R. B. Leslie, and A. E. Tynan rendered valuable assistance during field work. To these I extend my thanks.

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[2] It is suggested that these granites should be called, respectively, the migmatitic granite of the Mount Painter Migmatite Complex because of the demonstrable transformation of Adelaide System sediments into migmatitic granite between Mount Pitts and Mount Painter, and the Freeling Granite because of its intrusive nature and abundance of outcrops on the Freeling Heights.

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Fig. 1 A view from the northern boundary of the Terrapinna Migmatite Complex looking northward, over Terrapinna Waterhole (centre left) and the outcrop of the Tillite series, to the Mount Babbage Migmatite Complex and Mount Babbage (top left). Gently-dipping Eyrian Series is seen against the skyline and also at centre right. The dark ridge in the background is the outcrop of the fault zone between the tillites and migmatites.

Fig. 2 Outcrops of the migmatitic augen granite in the Terrapinna Migmatite Complex.

Fig. 3 The migmatitic augen granite of the Mount Babbage Migmatite Complex showing the large felspar augen.

Fig. 4 Microphotograph (crossed nicols) of migmatitic augen granite (9299), showing large microcline (right) and acid plagioclase (top left) crystals together with clear quartz and clusters of flakes of biotite. X 13.

Fig. 1 Outcrops of sheared migmatitic augen granite by Terrapinna Waterhole (looking south-west). The tillite-migmatite boundary is seen at centre right.

Fig 2 Outcrops of the Mudnawatana Granite in the banks of the Mudnawatana Creek.

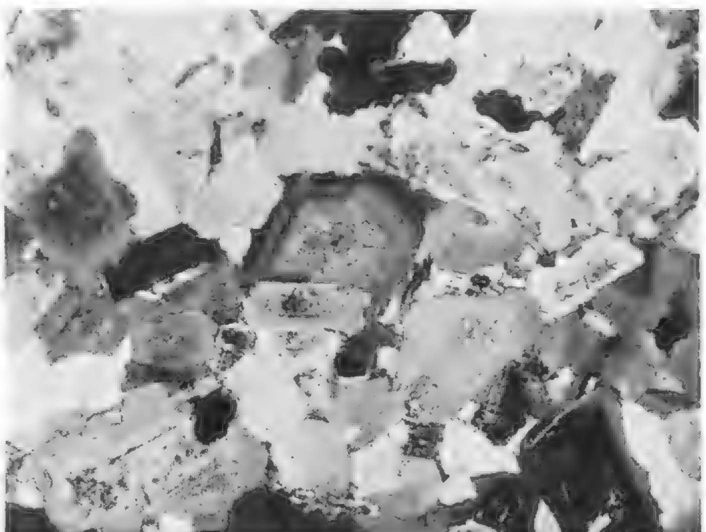

Fig. 3 Microphotograph (crossed nicols) of the Mudnawatana Granite (9380), showing its allotriomorphic-hypidiomorphic texture and the presence of zoned plagioclase, microcline, quartz and some mica. X 13.

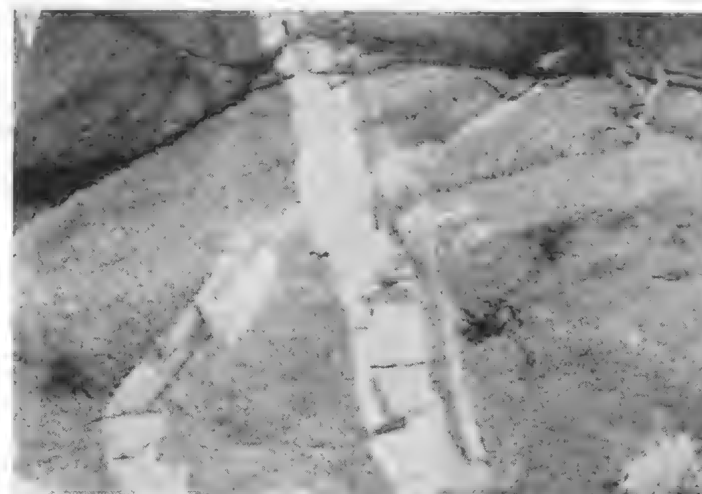

Fig. 4 Dykes of aplite cutting sheared migmatitic augen granite seen in the banks of the Hamilton Creek in the Terrapinna Migmatite Complex.

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THE WILLUNGA BASIN INTRODUCTORY AND HISTORICAL NOTES

BY DOUGLAS MAWSON

Summary

This contribution is in the nature of a general introduction to the paper in this volume by M.A. Reynolds: The Cainozoic Succession of Maslin and Aldinga Bays, South Australia, wherein he deals with the detailed mapping of sediments exposed in the coastal cliffs in the neighbourhood of Port Willunga. Attention is drawn to the nature of the Basin and to its importance in establishing the age and sequence of the Cainozoic sediments of South Australia. Reference is made to the author's early discoveries of fossil plant remains in the terrestrial arenaceous basal formation, the age of which is not younger than Eocene.

THE WILLUNGA BASIN
INTRODUCTORY AND HISTORICAL NOTES

By Douglas Mawson *

[Read 13 November 1952]

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SUMMARY

This contribution is in the nature of a general introduction to the paper in this volume by M. A. Reynolds: The Cainozoic Succession of Maslin and Aldinga Bays, South Australia, wherein he deals with the detailed mapping of sediments exposed in the coastal cliffs in the neighbourhood of Port Willunga. Attention is drawn to the nature of the Basin and to its importance in establishing the age and sequence of the Cainozoic sediments of South Australia. Reference is made to the author's early discoveries of fossil plant remains in the terrestrial arenaceous basal formation, the age of which is not younger than Eocene.

INTRODUCTION

Recently M. A. Reynolds, under direction of Dr. M. F. Glaessner, has completed a detailed map of the coastline cliffs of Maslin Beach and Port Willunga, part of the east coast of St. Vincent Gulf some 25 to 30 miles south of Adelaide. In this cliff face is exposed a rising succession of newer strata almost exclusively Tertiary and post-Tertiary in age resting with violent unconformity upon an undermass of highly folded Proterozoic and Cambrian sediments. These newer deposits occupy a basin-shaped depression extending from the coast of St. Vincent Gulf inland in a gradually narrowing area, to the vicinity of Mt. Bold.

The richly fossiliferous nature of much of these beds attracted the attention of geologists at an early date. In the first years of the University of Adelaide, Professor Ralph Tate in recording molluscan and other fossils of the Port Willunga area made it a type locality for Australian marine Tertiary strata.

STRUCTURE OF THE WILLUNGA BASIN

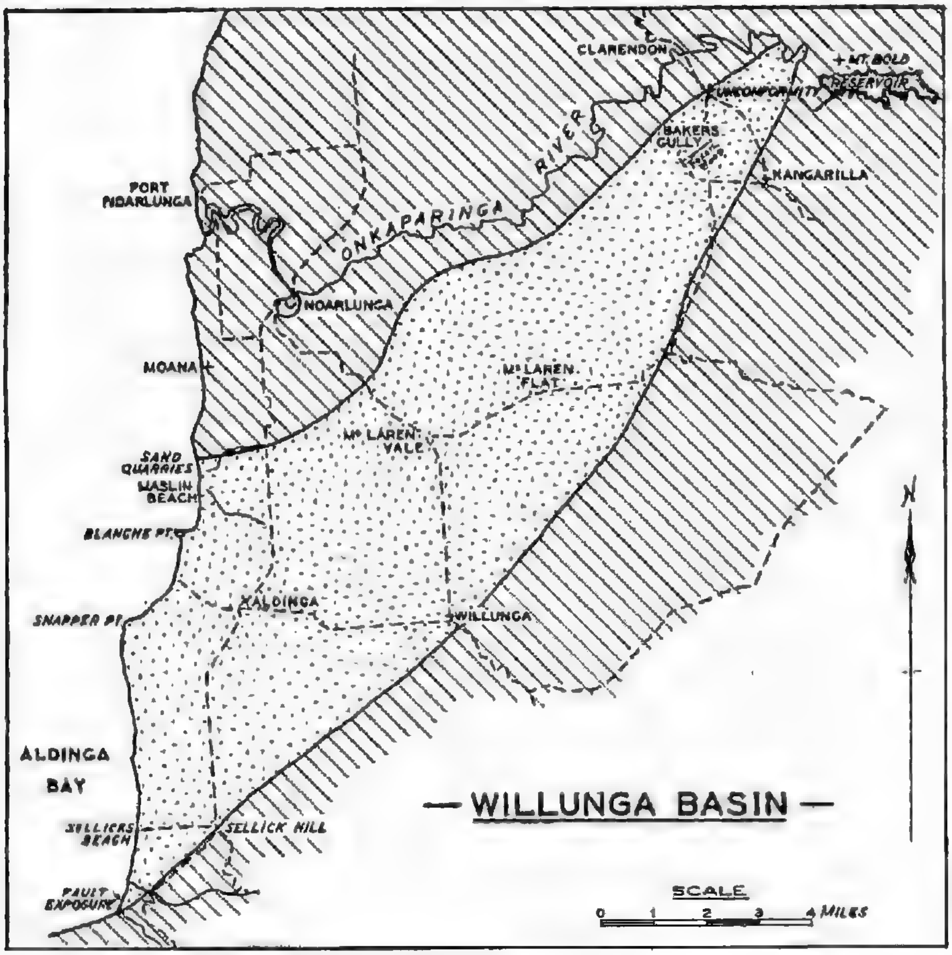
The Willunga basin, like the Eden-Moana fault block situated to the north of it, has long been regarded as mainly conditioned by faulting, which would appear to have proceeded by stages during the Tertiary era, resulting in the older sediments dipping more steeply than those of later date. W. N. Benson and Walter Howchin were the first to draw attention to the fault-block system of the Mt. Lofty Ranges. Later Dr. Charles Fenner dealt comprehensively and authoritatively with the structural features of the region.

In the past the main displacements have been regarded as about middle Pliocene in age. More recently, since marine Tertiary sediments overlying Permian tillite in the Upper Hindmarsh Valley have been recognised as depositions in a re-excavated glacial valley, the history of the Willunga Basin may well be more complicated than was formerly realised. Dr. Glaessner's detailed study of the Tertiary sediments of the basin now under way should go far to clear up this problem.

Some years ago R. W. Segnit (1940) advanced the view that the Willunga Scarp is a geomorphological feature resulting from glacial erosion, which he attributed to Cretaceous glaciation. In support of this claim he accepted as tillite a coarse shingle-type sediment which overlies the undermass rocks on the Sellick

* University of Adelaide.

Hill road at a shoulder of the scarp in the neighbourhood of the hotel. As no outcrop that we have observed in that locality has the characters of true tillite, and as no glaciated rock surface has ever been located along any part of the face of the Willunga Scarp, and as along the adjacent coast to the north there is a general dip of the Tertiary sediments towards the scarp, and as a fault line in the undermass is clearly defined at the foot of Sellick Hill near the south end of Sellick Beach we regard the Willunga Basin as mainly determined by faulting. In all probability Tertiary movements along the Willunga Scarp have been in the nature of periodic adjustments on a fault line initially established in the early Palaeozoic.



As, however, there is good evidence that erosion (generally accepted as Permian) contributed to the excavation of the adjacent Myponga, Upper Hindmarsh and Meadows valleys, it is probable that the Tertiary seas in the Willunga area transgressed a region already depressed and partly occupied by remnants of Permian glacial and glaciofluvial debris. That some of the Tertiary sediments of the area were derived in part from the re-working of Permian glacial deposits is suspected since the Maslin Beach brown sands are notable for heavy mineral residues similar to those derived from the weathering of the Permian glacials of Encounter Bay and Inman Valley.

At about 80 yards in from the shore along the main creek entering the sea (Hd. Myponga, Sect. 278) at the south end of Sellick Beach, there is exposed to view a good cross-section of what may be the main fault line along the foot of the Willunga Scarp. Here the creek is deeply incised in steeply-dipping Cambrian sediments. The creek cuts across the line of fault. Differential movement associated with the faulting has shattered the Cambrian rocks on each side of the fault line. The creek has cut its bed at beach level through the fault shatter zone back to the solid rock on the eastern side of the break. There the greater resistance of the unshattered rock has determined the existence of a small waterfall.

The exposure here is a good one. It presents an excellent example of the shattering effect of fault movement on the opposed rock faces. The shatter belt is about 50 yards wide. The central zone has, in the main, been reduced to the state of a pseudo-conglomerate; along the margin of the shear line the crushed rock is in the nature of a fault breccia.

YOUNGER SEDIMENTS OF THE WILLUNGA BASIN

The younger sediments occupying the Willunga Basin dip at low angles in a general south to south-east direction. Their contact with the older basement rocks is to be seen at the north end of Maslin Beach, but is best observed in the cutting on the Clarendon to Kangarilla Road, pl. viii, fig. 2, at about half a mile from the Onkaparinga crossing. The accordance of summit level of the uplifted block (Willunga Range) defining the eastern margin of the Willunga Basin is well illustrated in pl. viii, fig. 1.

The basal beds of the overmass sediments are almost everywhere terrestrial sandy types, often with a foot or two at the very bottom of a coarser pebbly nature. One such patch located due north of McLaren Vale township on the ridge overlooking the Onkaparinga River, though not well exposed is evidently of the nature of tillite and is taken to be a remnant of Permian glaciation. The pebble beds at the base of the white sands at the north end of Maslin Beach exhibit some features suggestive of re-worked glacigene deposits.

Professor Ralph Tate as early as 1876 worked on the Cainozoic sediments of Port Willunga, at that time more particularly referred to as the Aldinga area. He then (1878) summarised the succession in downward sequence as follows:—

1. "Lacustrine (?) clays, with no fossils; about 48 ft. thick."

   In more recent times this division has been referred to as Pleistocene mottled clay.
2. "Upper Series of calciferous sandstones and impure limestones with oyster bands; 22 feet in thickness."
3. "Lower Series of beds of a most diversified character: clays, limestone and sands rapidly replacing one another in horizontal and vertical extension; not less than 80 feet."

Later, in 1879, in attempting a correlation of the fossiliferous sediments of the Aldinga area with the Murravian (River Murray) beds, he divided his second and third series of the Aldinga succession as follows:—

Upper Murravian: the Upper Aldingan Series. Regarded at the time as of Upper Miocene age.

Middle Murravian: Polyzoal sand-rock, marls, etc., being the upper part of his earlier Lower Aldingan Series. Regarded as of Miocene age.

Lower Murravian: Earthy and glauconitic limestones, regarded as probably of Eocene age.

In 1896, Tate and Dennant when dealing in greater detail with the beds exposed in the cliffs of Port Willunga, relegated the beds to two divisions only: the lower "Eocene," and the upper "Miocene"; the latter lying with slight angular unconformity above the lower "Eocene" beds.

In his last paper Tate (1889) subdivided the beds of the Aldinga area into Miocene, Upper Eocene (upper part of the Lower Aldingan), Middle Eocene (Middle section of the Lower Aldingan), and Lower Eocene (lower part of the Lower Aldingan Series).

In these age determinations Tate followed the Lyellian method based on the percentages of recent forms found in the respective beds. In adopting this method he was, however, greatly handicapped for, in his day, the record even of the existing forms of mollusca along Australian coasts was very imperfect.

At about the time of Tate's death Frederick Chapman, then an accepted authority on the foraminifera, arrived in Australia to become palaeontologist to the National Museum, Melbourne. He immediately engaged upon an exhaustive study of the foraminiferal contents of Victorian Cainozoic sediments. He was interested in establishing with greater reliability the age of Australian marine Tertiary formations to be based on their foraminiferal content, the chronological value of which had, even at that time, received general acceptance.

Chapman soon turned his attention to the Port Willunga beds of South Australia. He then (1914 a and b) correlated Tate's "Lower Aldingan Series" with his Victorian Miocene (Janjukian) localities and included Tate's Upper Aldingan Series with the Kalimnian (Lower Pliocene). Thereafter, for many years, Chapman's age grouping for the marine Tertiaries of South Australia was generally adopted. On this basis, in the area now under discussion, the upper fossiliferous series was accepted as Lower Pliocene (Kalimnian). The Lower Calcareous Series, separated from the former by a slight unconformity, was regarded as Miocene (Janjukian).

Howchin, in 1923, referring to arenaceous beds underlying Chapman's Miocene Series, showed that the brown sands above passed down into white sands immediately overlying the older "quartzite bedrock." He indicated the possibility of the brown sands being of Oligocene age.

About this time, during one of our annual student excursions to Maslin Beach when there happened to be an exceptionally low tide, and when the usual superficial veneer of beach sand had been removed by storm waves, we had an exceptional opportunity of examining the brown sand formation. The richness in glauconite in some of the area exposed and vague fossil forms appearing as glauconitic replacements suggested the possibility of a Cretaceous age. Accordingly supplies were sent to Chapman for examination, but he failed to find any forms specifically Cretaceous.

In 1925 the author examined the white sand formation at the base of the sequence at the north end of Maslin Beach, with a view to the employment of the sand in building construction. Subsequently the Noarlunga Sand Quarries came into operation. The existence of about 50 feet of useful sand of terrestrial fluvatile origin was established and its relation to the overlying brown sand checked. The latter was accepted as deposited under marine conditions in a shallow transgressing sea. Current bedding, a marked feature of the white sand formation, was interpreted to indicate the flow of water at the time of deposition to have been in a general west to east direction.

By the year 1930 the white sand formation was well exposed by quarrying. At the base was exposed a pebble band containing many highly polished (glazed) quartzite pebbles, some of which are faceted, suggesting erratics. On one of these facets, striae, probably glacial in origin, are still discernible. The quartzite of the

pebbles corresponds in character to that of very later Precambrian or lower-Cambrian age outcropping on the coast at the northern limit of Maslin Beach. It was thus concluded, even as early as 1930, that the basal pebble band met with in the sand quarry may have been derived in part from the erosion and redistribution of Permian tillite.

Intercalated in these sands are occasional thin lenses of white pipeclay. None are of any considerable lateral extent and none exceeded 6 inches in thickness, usually much less. In these we discovered plant leaf impressions. These plant fossils are mainly in the nature of impressions on the white pipeclay, retaining some indication of venation. Less frequently there remained some brownish to blackish carbonaceous residue. The author in 1932 despatched this material to Chapman for identification. In due course he (Chapman 1935) identified seven distinct plant species.

At this same time further specimens, some containing poorly preserved fossils of the overlying glauconitic brown sands were submitted to Chapman. He reported that these sands recalled the Upper Oligocene of borings at Lakes Entrance, Gippsland, and could be regarded as of that age. The underlying white sands with fossil leaves he then relegated to the Lower Oligocene.

About this time the University received through Dr. Charles Fenner, a splendid example of a leaf impression embedded in ferruginous sandstone obtained a little way above the base of the basal sandstones of the Willunga Basin close to their unconformable contact observable on the Kangarilla road (Sect. 758, Hd. Kuitpo). This fossil he referred to (Fenner, 1935) as *Magnolia browni,* stating that this fossil form "was formerly regarded as Cretaceous but now known to be Miocene."

At about this time also the author located abundance of detrital silicified plant remains (wood) in the Bakers Creek gravel pits. In these gravels the fossil wood is detrital, but we traced it to its original setting, a definite horizon in the sandy beds in Sections 826 and 827, Hundred of Kuitpo. There a number of pieces of silicified wood were obtained *in situ.* The material collected includes large root masses and stems. It has not yet been dealt with by a palaebotanist. One of the commonest forms appears to be the silicified stems of *Banksia,* while others suggest the underground developments of a variety of yacca. Field reconnaissance appeared to indicate that the terrestrial sandy beds with fossil wood and leaves at the base of the Willunga Basin sediments near Clarendon are equivalents of the yet unconsolidated sands of the sand quarries at the northern end of Maslin Beach. We have, therefore, in the past, correlated them with Chapman's Lower Oligocene division.

At a date subsequent to the submission to him of fossil leaf remains from the White Maslin Sands a series of specimens from typical fossiliferous horizons of the Port Willunga marine beds were again submitted to Chapman. He, in association with Miss Irene Crespin, was not able to vary to any great extent his earlier age determinations; they were clearly decided, however, that the base of Tate's original Aldingan Series was of Oligocene age.

In the early 1940's Miss Irene Crespin made a hasty visit to the area but found nothing in the material collected to suggest notable modification of the earlier findings of herself and Chapman.

More recently, in co-operation with the Mines Department of South Australia, she has made further investigations, the result of which has not yet appeared.

Then came the discovery by Victorian geologists of marine Eocene fossils at the base of their Cainozoic sediments. Mr. Walter J. Parr was the first to find the Eocene foraminifer *Hantkenina alabamensis* in the Victorian beds. In Decem-

Fig. 1

Fig. 1. The very obvious unconformity on the Kangarilla Road almost one mile beyond Clarendon. Here the curved, steeply dipping slates of late Proterozoic age are capped with early Cainozoic sandstone. A thin pebble bed forms the base of the latter. View looking southeasterly.

Fig. 2

Fig. 2. Part of the splendid cross-section exposure on the major fault line flanking the Willunga Range. This is located 80 yards in from the shore, along a creek at the southern end of Sellick Beach. The rock traversed by the fault is Cambrian slate. To the left is a marginal belt of crush-breccia. To the right is the central crush-conglomerate.

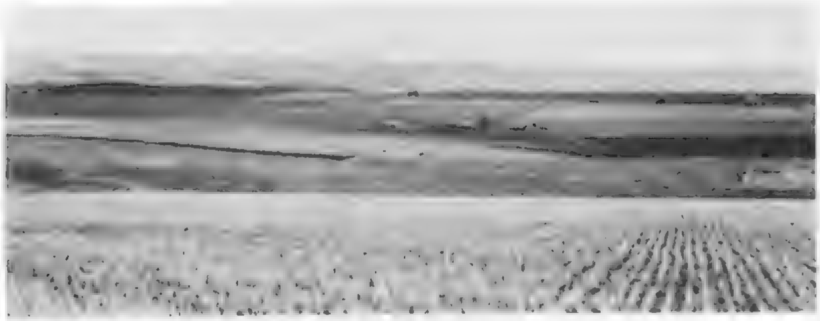


Fig. 1. View looking south across the Willunga Basin from the higher slopes on its north side. The elevated peneplain (about 1,200 ft.) of the Willunga Range forms the distant skyline. The overmass rocks occupying the basin reach elevations up to 500 feet above sea-level.

Fig. 2. Cross - section through the lower members of the Willunga Basin sediments at the north end of Maslin Beach. View (taken in 1925) looking up the steep gully, where later Noarlunga Sand Quarries Ltd. operated. At the base is a thin formation of pebble bearing sands in which some of the pebbles are faceted. In one case faint, almost obliterated, glacial striae are discernible, suggesting a Permian glacio-fluvial origin or redistribution of earlier glacial debris in late Mesozoic or early Cainozoic time. The lower and main thickness exposed is not younger than Lower Eocene. The sand beds continue upwards to the Pliestocene mottled clay capping, which in the photograph appears as a uniform dark bed.

ber 1948 he visited South Australia with a view to re-examining the Port Willunga beds. With the author he collected a close succession of samples of the marine limestones. A few weeks subsequently he reported the finding of *Hantkenina alabamensis* in one of the samples taken from near the base of the calcareous fossiliferous beds overlying the brown sands to the north of Blanche Point. Unfortunately, Parr did not live long enough to complete the examination of all the samples that he had collected at Port Willunga. He had, however, apparently indicated the existence there of an Eocene horizon.

At this stage Dr. Martin F. Glaessner joined the University of Adelaide and has brought to bear on the problem of the age of these beds his wide knowledge of palaentology and stratigraphy.

So much of this State is occupied by these Cainozoic fossiliferous marine beds that their detailed elucidation is of great significance to South Australian geology. Thus it is gratifying to note that the problem is now well in hand.

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THE CAINOZOIC SUCCESSION OF MASLIN AND ALDINGA BAYS, SOUTH AUSTRALIA

BY M. A. REYNOLDS

Summary

After a general description which includes the Pre-Tertiary Basement, the succession, its structure as shown by dip measurements, and the physiography of the area are discussed. The main part of the paper deals with the division of the succession into 8 units with appropriate sub-divisions, and these are discussed in detail, with descriptions of exposure, lithology, fauna, contacts and thickedness of each unit. These lithological units are listed in Table I. Some consideration is given to the faunal assemblages which they contain and restricted larger fossils are listed in Table II. The conditions of deposition are then considered and the stratigraphic relations are briefly reviewed.

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551.77 (942)

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I INTRODUCTION

Detailed stratigraphic investigations in the coastal areas south of Adelaide were carried out by the writer in 1951 in the course of his studies for the Honours Degree of Bachelor of Science in the University of Adelaide. This area had attracted attention of palaeontologists and stratigraphers since it was described by Tate (1878, 1879, 1899; see also papers by Tate and Dennant, Howchin, Chapman and others). The work was based on a plane-table survey. A structural profile section was constructed and the main stratigraphic observations presented in the form of columnar sections. Many fossils, larger as well as microscopic, were collected but not all of them could

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be identified in the time available for this research. Its main objective was the establishment of the sequence of strata, their stratigraphic relations, lithological characters and thicknesses.

ACKNOWLEDGEMENTS

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II GENERAL DESCRIPTION

1 Pre-Tertiary Basement

To the north of the sand quarry at Ochre Point there are steeply dipping Pre-cambrian chocolate shales overlain by a greyish-green grit with limonitic bands, a hard grey to reddish quartzite and consolidated to friable sandstones, the latter being somewhat obscured by recent deposits. They have a dip of approximately 50° in a direction 121° (true). From observations made immediately to the north of the sand quarry, it is suggested that the sandstones are probably the source of some, at least, of the quarry sands. These beds, tentatively called Pre-cambrian, are not, however, regarded as directly underlying the white sands. A clayey bed, locally known as pipe-clay, which does not show bedding, is exposed in the pit used as a loading ramp adjacent to the elevator and loading construction, and in a small drain running westerly from the quarry, below the bridge west of the building.

A measurement of the height of the base of the sands was made in a pit east of the elevator and loader, but this pit has since been cemented in. The bed has a purplish stained appearance and shows Liesegang rings. Polished quartz pebbles and cobbles are occasionally found within this bed and small lenses of sandy material may be seen. One such cobble was taken from approximately 7 feet from the top of this bed (sample number A.182 [1]). The unstratified and unsorted nature of this bed, together with the fact that occasional erratics are found, indicates strongly that this is a glacial till. Since it is similar in appearance to the till at Hallett Cove, I have tentatively classed this bed as ?Permian. This bed is 14 feet thick and is underlain by a fine sand at least 12 feet thick. These measurements were made in a well in the quarry to the west of the elevator and loader and are taken from Dr. K. R. Miles' report on the Noarlunga Sand Deposit (1945).

2 Cainozoic Succession

Gently dipping Pre-Pliocene Tertiary sediments overlain unconformably by almost horizontal Pliocene sands and limestones which are capped by approximately flat Pleistocene (?) and recent sediments are to be seen for a greater part of the coastline between the sand quarry and Snapper Point. This succession is described in detail in the following pages.

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[1] Samples and grid slides with foraminifera have been deposited in the Palaeontological collection of the University of Adelaide.

3 Structure

In a section such as this where the dip rarely exceeds 5° and where, in most cases, apparent dips only have been measured, the determination of structure and calculation of the thicknesses of beds present considerable difficulties.

Observations made in the cuttings at the bottom of the sand quarry suggest that the base of the North Maslin Sands has a slight dip towards the north-west. Accurate determination of this dip will be possible should the floor of the quarry be cut below its present level, and the base of the sands reached in other parts of the quarry.

The dip of the base of the overlying brown and green sands is also difficult to determine because the contact between the two formations is evident only in three places. Information from the bore records cannot be used because there is insufficient evidence to indicate where the actual contact occurs and the contact, although it occurs over a probable distance of approximately 20 chains, is masked by overlying Recent deposits. However, the contact has been revealed in the south of the quarry, where it has a dip (true) of 7½°, 201° (true), in a small stream-course immediately south of the quarry, and also at the base of the southern wall of the gully (locally known as the "Canyon") at its westernmost extremity. By calculation of the heights above mean sea level of the contacts at these exposures, approximately 88 feet at the sand quarry, 20 feet at the gully, and due to the fact that the brown sands are exposed down to a height of less than 50 feet on the small limonite-capped hill south of the quarry, it is estimated that the dip of 7½° as seen in the sand quarry quickly flattens to a dip of not more than 2°. This estimation was made along the line of true dip.

The top of the brown sands is irregular and the dip has been calculated on a regional scale by estimation of the height at three points and using the method outlined by Lahee (1931, p.635). The strike is approximately 162° true and the dip approximately 2°. Overlying the brown sands are polyzoal sands and limestone becoming glauconitic towards the top. There are transitional marls above the glauconitic limestone and these are overlain by the banded hard and soft marls which form Blanche Point. The dip of approximately 2° remains constant throughout these beds but there is a gradual change in the strike. The top of the glauconitic limestone strikes approximately 145° whilst the banded marls have a true strike of 139°. Conformably above the banded marls are the soft marls which have, at their upper limits, an apparent dip of 1½° approximately in a direction 195°.

The freshwater red sands and clays exposed in Chinaman's Gully have, at the top, a dip of 2°-3° (200° true). This was measured by Abney Level on a platform which is exposed just north of Aldinga Creek during winter months. Estimation of the dip of the overlying polyzoal beds from here south to where they pass below sea-level is impossible by the use of Lahee's method because the coastline may be regarded as almost straight. The only platform from which dip may be determined in a similar manner to the method used on top of the Chinaman's Gully beds occurs just north of the prominent point approximately ⅓ mile south of the remaining jetty piles at Port Willunga. The dip here is still 2°-3° but the strike is approximately 063° (true). The reefs which occur in the vicinity of the polyzoal sandy beds confirm the south to south-eastern dip direction.

4 Physiography

The coastline from the sand quarry to Snapper Point consists principally of youthful cliffs cut in the sediments already briefly described. More resistant beds, such as the Pre-cambrian quartzite at Ochre Point, the Blanche

Point Banded Marls and the hard sandy limestone at the top of the Pliocene beds, form prominent points whilst less resistant beds have been eroded away to form embayments in the coastline in this section. The hard polyzoal and glauconitic limestones and harder bands in the Blanche Point marls and in the Port Willunga polyzoal beds form reefs, some of which are rich in marine life, from just north of Blanche Point at varying intervals to Snapper Point where the upper hard sandy Pliocene limestone forms an extensive reef. From observations made at low tide from on top of the cliffs at Snapper Point, this latter reef appears to be the crest of a very slight anticline which plunges seaward.

The general succession is interrupted by the mouths of three creeks. The northernmost of these, about 500 yards south of the sand quarry is known locally as the Canyon, due, no doubt, to the fact that the walls of the cutting are almost vertical. The outlet to Bennett's Creek breaks the succession 500 yards south of the Canyon whilst just below Port Willunga, at the northern limits of the township, the Aldinga Creek enters the sea. Whilst water flows from these creeks into the sea after heavy winter rains, the outlets are generally separated from the sea in the drier seasons of the year by sand. There is evidence to suggest that each of these creeks was of larger dimensions in Post-Pleistocene times. Small streams traverse the section at Maslin Beach and between Blanche Point and Port Willunga The cuttings formed by such streams are not generally important but in Chinaman's Gully and two cuttings immediately north of it, good exposures of the second non-marine formation are revealed.

Above the cliffs, the coastal section area is relatively flat, undulating only where traversed by creeks. A thin layer of kunkar underlying Recent soils and deposits is almost continuous throughout this area, and, apart from the undulations, it has a regional dip of only 1 in 200 feet from the sand quarry to Snapper Point. Generally the basal parts of the section may be regarded as wave-cut cliffs. However, the effects of other erosive agents may be seen in the upper parts of the section and where the basal parts of the section are composed of sands. Just south of the sand quarry the basal beds are composed of the brown sands and, although limonitic bands provide a certain amount of protection against erosion, small hilly slopes with moderately steep inclination have been formed between streams; such hillocks are capped with limonite. Between the Canyon and Bennett's Creek, these sands receive a certain amount of protection from the capping of Pliocene limestone but from Bennett's Creek to the trig. point, this capping does not exist and the erosional effects of the small streams and their tributaries beginning in the overlying ?Pleistocene clays have produced rounded valleys with steep sides between protruding spurs. These valleys resemble hanging valleys elevated above beach level by the rapid erosion of the lower beds by wave action. From the trig. point to almost the southern limits of Maslin Bay and from Blanche Point to Chinaman's Gully, platforms have been formed above the hard upper layer of Pliocene limestone. The overlying ?Pleistocene clays are being eroded away and form a series of rounded protuberances with steep sides between stream courses. The erosion of the ?Pleistocene clays is occurring in a similar manner along the length of Blanche Point and from Chinaman's Gully to Snapper Point. Along these portions of the section the lower beds are more resistant to the effects of waves and consequently, over a long period, they have become the protruding points mentioned at the beginning of this discussion. They thus become exposed to the full effects of wave action with the resultant production of almost vertical cliffs which are continuously being eroded away. It is because of this that such platforms as have been formed above

the hard upper Pliocene limestone in those parts of the coastline described earlier as embayments, have not had the opportunity of being formed in these portions. The steep nature of most of the ?Pleistocene clay deposits is due to the thin protective layer of kunkar which underlies the Recent soils.

Sand dunes and banks occur at various intervals along the base of the section during the summer months and obscure certain beds in the succession. However, where such deposits are purely aeolian and not covered by vegetation, they will be removed together with a greater part of the beach sand by the high seas generally occurring during winter months. Sand hills and recent deposits covered with vegetation are present in the northern parts of Maslin Bay and to some extent between Blanche Point and Port Willunga.

Land-slides have occurred throughout the section with the result that, in some places, lower beds in the section have become obscured by ?Pleistocene clays, whilst in other places cliff faces have collapsed and produced the same effect. The fallen blocks, which occur amongst the scree at the base of such collapsed faces, have been used for the correlation and sampling of such beds in the section to which they can be proved identical, where such beds are inaccessible. A certain amount of obscurity as to the nature of beds in cliff faces has occurred as a result of surface weathering.

A small shallow cave exists near the south-eastern corner of Maslin Bay where sands underlying the polyzoal limestone have been eroded away. A deep cave has been tunnelled through the polyzoal and glauconitic limestones and overlying softer transitional marls along the northern side of Blanche Point, and further west above a reef formed by the limestones the soft, transitional marls have been eroded away, leaving a large shallow cutting beneath the overlying banded marls. The only other caves occurring in the section have been tunnelled in the polyzoal beds below Port Willunga by fishermen.

Fresh to saline water has been observed emerging from above the glauconitic limestone reef in the large shallow cutting immediately north of Blanche Point and from the polyzoal beds in the vicinity of the first reef, locally known as "Spring Reef," south of the old Port Willunga jetty.

To the north-west of Blanche Point is a remnant of a former extension of the banded marls, which is known as Gull Rock.

A Low Water Mean Line is included on the map to indicate those portions of the coastline which are generally inaccessible due to the sea. At times of lower than Mean Low Water tides, however, the reef just north of Blanche Point is exposed above sea level and it is possible to examine beds almost to Blanche Point.

There are two series of minor faults, one just below Port Willunga township, the other approximately a quarter of a mile south of the piles of the former jetty. The greatest of these faults has a throw of only 9 feet, this being the displacement on the southern side of the downfaulted block (graben) below Port Willunga. The faulting occurred in Pre-Pliocene times although there is evidence to suggest that in the southernmost series there was a slight displacement in Pliocene or Post-Pliocene times. This is indicated in a slight downthrow of the Pliocene beds between the two greater of the series of minor faults. All faults dip steeply to either the east or the west and the strike, as measured by prismatic compass, is north-south in the case of the larger, more prominent faults. Whilst there is no evidence of a continuance of these faults at Blanche Point, prominent fracture lines extend here in a more or less north-south direction, i.e., in the general direction of the minor faulting.

III. STRATIGRAPHIC OBSERVATIONS

Under this heading it is intended to subdivide the succession into a number of lithological units and to name the pre-Pliocene Formations (but not their subordinate Members) according to the Australian Code of Stratigraphic Nomenclature (Raggatt, 1950). After the completion of his thesis the writer was informed of Miss I. Crespin's intention to publish stratigraphic names for the succession here described. The name "Maslin Sandstone" will be given by Miss Crespin to the combined North Maslin and South Maslin Sands of this paper. The Pliocene strata will be formally named by Miss Crespin. New names are here proposed for the pre-Pliocene Formations as these are smaller and more detailed that the more comprehensive divisions recognised by Miss Crespin. No attempt has been made to give a time and time-rock classification to the majority of these units because time has not permitted a full enquiry into the ranges of index fossils. (See Table I and Fig. 1.)

Formation 1: North Maslin Sands (First Non-Marine Formation)

Exposure—From the Noarlunga Sand Quarries Ltd. quarry situated approximately 50 chains south east of Ochre Point to the base of the southern wall of the Canyon at its western limits. Dr. Miles (1945) mentions an exposure "at the mouth of a gully, just above the beach level" immediately south of the quarry, but this was not observed. However, the sands at their upper contact are exposed in the stream course just below the road leading into the quarry.

Lithology—Cross-bedded sands varying in grain-size from pebbles to very fine sands with the coarsest particles at the base of individual beds. Fine silty clay bands and yellow clay lenses occur at a height of approximately 10 feet from the base; the former have a laminated appearance and are somewhat flexible; the latter are sometimes nodular, and such clays occasionally yield fossilized plant remains. These are best seen in the northern parts of the quarry. According to Miles (1945): "The sand throughout the deposit is substantially free from organic material, and, for the most part, is sufficiently fine and free from clay substance to be used as ordinary building and concrete material without screening." The sands are predominantly white but variously coloured bands and lenses occur more pronouncedly in the upper beds.

Flora—Chapman (1935) described some plant remains sent to him by Sir Douglas Mawson. Such remains are not as abundant as Chapman suggests in the "pipe-clay" which occurs towards the base of the sands. ("Pipe-clay" has been used in quotation marks because it is most probable that this is the clay occurring at an approximate height of 10 feet from the base of this formation and not the basement rock, which is known locally as pipe-clay.) Clays with fossilised plant remains have been seen east of the elevator in the gully which leads towards the "Flying Fox." These should not be confused with the silty bed which contains lignitic material occurring at the top of the Pliocene sands.

Contacts—The base of this formation is marked by a band of smooth polished quartz pebbles lying unconformably above the ?Permian till and is exposed in cuttings adjacent to and west of the loader and elevator. As exposed in the southern parts of the quarry just below the base of the Pliocene sands, a transition occurs between the upper parts of the North Maslin Sands and the overlying limonitic quartz sands which are green at the base.

TABLE I

UNIT No.		FORMATION	MEMBER	LITHOLOGY	THICKNESS (Feet)
8		? Pleistocene and Recent Deposits		Mottled red and green clays and sands and Recent deposits	59 maximum
		FORMATION	MEMBER		
7		Pliocene Limestones		Limestones and sands with some clays	18–20
			Angular Unconformity		
6		Port Willunga Beds		Sandy, polyzoal and clayey cross-bedded sediments varying in composition and colour	111½
5		Chinaman's Gully Beds		Gravels to silts with red, yellow, brown banded clayey beds — 2nd Non-Marine Beds	5½ maximum
	C		Soft Marls	Soft marls with one hard band and hard nodules	57
4	B	Blanche Point Marls	Banded Marls	Alternate hard and soft bands, some of the former being siliceous	37
	A		Transitional Marls	Limey glaueonitic marls to marls	7½ maximum
	B		Glauconitic Limestone	Richly fossiliferous green glauconitic limestone	3 maximum
3		Tortachilla Limestones			
	A		Polyzoal Limestone	Richly fossiliferous polyzoal sands and limestone	3–6
2		South Maslin Sands		Mainly brown limonitic quartz sands, green and purple in part	100–160 average
1		North Maslin Sands		White gravels and sands with some clay lenses — 1st Non-Marine Beds	64 approximate
				Total :	388½–451½

Thickness—As already mentioned under the discussion of Structure, the true dip of the base of these beds is not determinable and true thickness cannot be measured. The height of the base as measured in a temporary cutting east of the elevator and loader during the plane table survey is 26 feet. Since the height of the base of the Pliocene would be approximately 90 feet (by estimation from measurements made to the south) in this vicinity, the thickness of this formation is given as approximately 64 feet.

Remarks—Chapman's suggestion of Lower Oligocene age for this Formation is in conflict with later foraminiferal evidence which indicates Upper Eocene age of the Tortachilla Limestones.

Formation 2: South Maslin Sands

Exposure: This formation extends from the southern parts of the sand quarry to the small shallow cave in the south-east corner of Maslin Bay, a distance of almost 1¼ miles.

Lithology—The sands consist predominantly of well-rounded grains of quartz and limonite loosely consolidated with a calcareous cement. The minerals occur in approximately equal amounts in the sands but there are other constituents including small green clay pellets, pebbles of quartzite, etc., which occur in small amounts. Whilst these beds vary from a gravel to a fine sand, they are predominantly coarse to very coarse sand. The color varies from mainly brown, due to the limonite, to green and light-purple which colors apparently arise from staining of the calcareous cement. Cross-bedding occurs throughout the formation and pebble bands frequently form the base to successive beds. Thin laminae of limonite, often rich in quartz grains, form a capping to successive beds in the lower parts of the formation, and these, together with the pebble bands, emphasise the cross-bedding. Such limonite bands, as mentioned under Physiography, form a capping to the small hilly slopes south of the sand quarry. There is a brown earthy bed one foot thick which contains quartz pebbles, 3 feet above the base of the formation. This is probably a bed of fresh-water origin occurring in the transition from terrestrial to marine environment.

Glauconite, as such, has not been observed in the sands, but it is believed in view of the similarity in properties of some of the limonite grains to those of glauconite, that this mineral may have been originally deposited or formed. A sample of the "green-sand" overlying the "pipe-clay" and sands in the Maslin Bay quarry was also sent by Sir Douglas Mawson to Chapman (1935) who ascribed the shape of many "glauconitic" casts to the infilling of foraminiferal tests, "whilst others are replacements of ovoid pellets variously ascribed to the excreta of worms, echinoderms or fishes." He also suggests that "these pellets are similar to those found in the glauconites and marls of Upper Oligocene age in the borings at Lakes Entrance, Gippsland." Edwards (1945), in a discussion on the Glauconitic Sandstone of the Tertiary of East Gippsland, Victoria, describes, with illustrations, the formation of glauconite from biotite and mentions three facts:

(1) Faint traces of biotite cleavage are retained by glauconite,
(2) glauconite can develop a mammillated outline, and
(3) "As the gelatinous glauconite dried, it shrank, developing rounded edges and shrinkage cracks."

Further, the same author points out ". . . . glauconite is an unstable mineral which readily alters to limonite or ferruginous clay if exposed to oxidising conditions, so that this a normal change for glauconite to undergo." Some limonite grains exhibit the latter two, of the three properties outlined above, and since the change from glauconite to limonite under oxidising

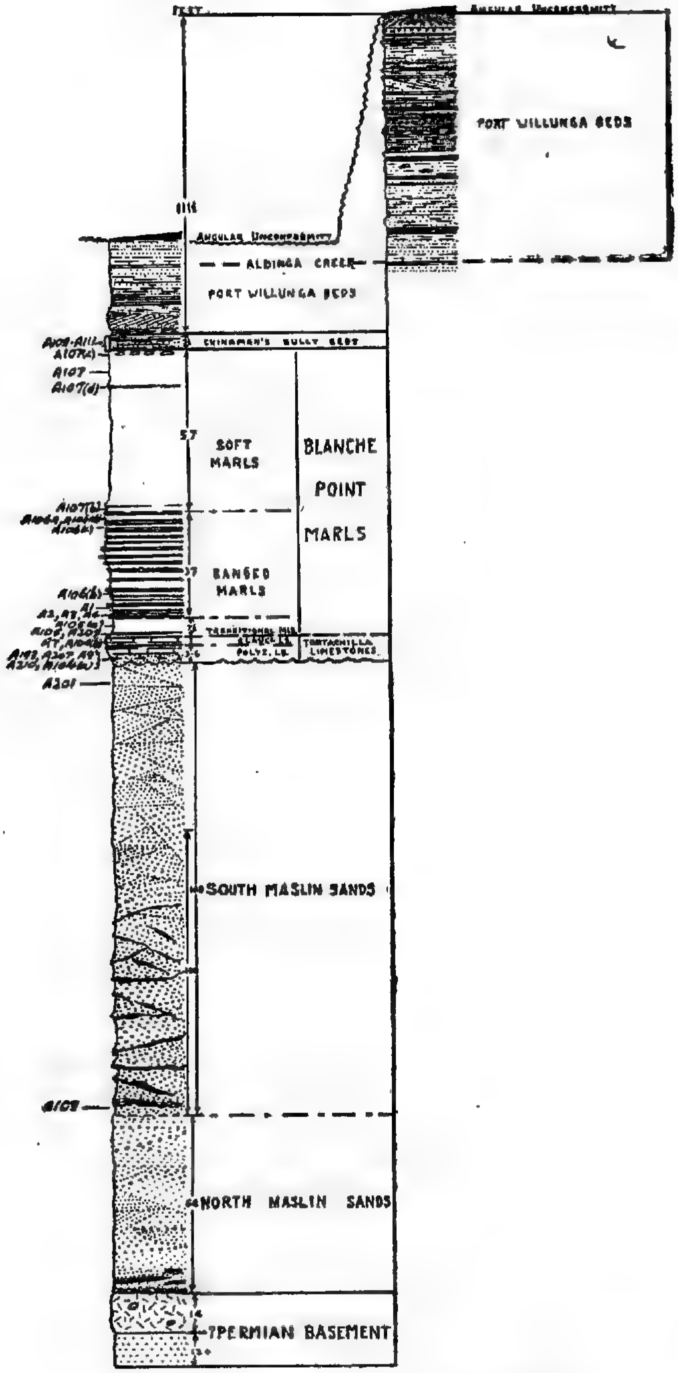


FIG. 1. COLUMN OF PRE-PLIOCENE BEDS.

conditions is a normal one, the above statement that glauconite may originally have been deposited or formed is substantiated. It is not known whether such alteration occurred during or after deposition.

Fauna—Fossil remains, although by no means plentiful, occur throughout the formation. Washings of samples from various horizons have revealed

the presence of foraminifera, echinoid spines, sponge spicules and polyzoa. Sample A103 from the basal beds yielded *Gyroidina?* and others (undet.), whilst casts of Polymorphinidae, similar to those found in the polyzoal sands immediately above this formation, are common in the uppermost beds (Sample A201) exposed just above "Uncle Tom's Cabin" towards the south of Maslin Bay. Lamellibranchs, generally fragmentary, have been noted from various horizons, one occurring at beach level between the trig. point and the first boat shed to the south. *Lima bassii* (T. Woods) var.b. (Tate) and *Barbatia* sp. (samples A188, A208 respectively) have been identified. Small gastropods have also been collected.

Contacts—In the southern parts of the sand quarry, there is a sharp transition from the underlying North Maslin Sands to a green sand bed with white nodules which bed constitutes the base of the South Maslin sands. The upper beds are overlain unconformably by a polyzoal limestone which is brown and unconsolidated at its base in places. The junction of this unconformity with the angular unconformity at the base of Pliocene beds is not exposed but is thought to exist on the southern side of the spur immediately below the trig. point. The upper contact, however, may be seen from just south of this spur to the south-east corner of Maslin Bay.

Average Thickness—By calculation, 100-160 feet.

(Note: The methods of determination of thicknesses are given in detail in the original thesis, copies of which have been deposited in the Barr Smith Library, University of Adelaide.)

Remarks—Howchin (1923) regarded this formation as a freshwater series, but rare remains of marine fossils have been found throughout the formation, which is now regarded as dominantly marine.

Formation 3: Tortachilla Limestones

Member 3A: Polyzoal Limestone

Exposure—From just south of the spur below the trig. point to the north side of Blanche Point where it is exposed from the beach to the small cave about 100 yards east of Blanche Point. The upper parts of the bed are exposed at low tides as an almost flat reef which extends from just west of the cave to just east of Blanche Point. This member is not exposed south of Blanche Point.

Lithology—From the base upwards this member consists of unconsolidated polyzoal sands rich in limonite grains grading into a hard, richly fossiliferous polyzoal limestone which becomes partly glauconitic towards the top. The limonite grains are less abundant in the upper parts and hence the color also grades from the base upwards from predominantly brown to pinkish-white. In thin section quartz grains are seen to be present to almost the same extent as the limonite grains in the upper consolidated limestone. Sections of microfossils are plentiful and occur with the above-mentioned minerals in a richly calcareous matrix.

Fauna—

Casts of different species of Polymorphinidae similar to those occurring towards the top of the underlying sands; and others (A210, A9) —*Terebratulina* sp., *Terebratulina lenticularis* Tate, *Magadina* sp., *Magellania tateana* (Tenison-Woods), *Ostrea* sp., *Aturia clarkei attenuata* Teichert and Cotton was obtained from approximately 3 feet above the base of this formation just above "Uncle Tom's Cabin" by Dr. M. F. Glaessner and identified by him. *Pseudechinus woodsii* (Laube), *Fibularia gregata* Tate, *Australanthus longianus* (Gregory),

Echinolampas posterocrassus (Gregory), *Eupatagus* sp. (*a*) are common. Other fossils include an alcyonarian coral, a comatulid crinoid, crinoid stems, many species of polyzoa, sponge spicules, gastropod casts, ostracodes and shark's teeth.

These fossils occur in my samples Nos. A104(a), A193, A207, A210 and Nos. A7 and A9 (collected by Dr. Glaessner).

Contacts—The formation is unconformably underlain by the South Maslin Sands. The change from Polyzoal upward to Glauconitic Limestone is transitional and the two units are regarded as Members of a Formation.

Thickness—The maximum thickness of 6 feet is to be seen in the south-east corner of Maslin Bay where the basal polyzoal limonitic sands show their greatest development in a trough of the unconformity which is somewhat sinuous. These sands vary in thickness from 3 inches to 3 feet whilst the consolidated limestone above generally has a thickness of 3 feet, hence the thickness of the Member is given as 3 to 6 feet.

Member 3B: Blanche Point Glauconitic Limestone

Exposure—This member is exposed over almost the same distance in Maslin Bay as the underlying Polyzoal Limestone. It may be seen from about 250 yards south of the Trig. Point almost to Blanche Point where the lower parts form the top of the reef already mentioned under 3A. Just east of the small deep cave 100 yards east of Blanche Point along the northern side, this member forms the top of a small platform.

Lithology—This is in general a hard calcareous rock rich in glauconite, hence the predominant green color. It is very fossiliferous and there are some small pockets of softer glauconitic material similar to those occurring in the upper parts of the underlying polyzoal limestone. There are some grains and pebbles of limonite and quartz in this rock also, and in some cases fossil tests which have not become infilled with glauconitic clay show a secondary formation of calcite in clear crystalline form.

Fauna—

FORAMINIFERA: *Uvigerina, Angulogerina, Anomalina, Astrononion, Pullenia, Siphonina, Gyroidina, Nonion, Discorbis, Eponides, Bulimina, Gümbelina, Bolivina, Bolivinita* and others. (A7).

POLYZOA: *Reticulipora transennata, Lichenopora* sp.

CORALS: Tate (1878) lists *Amphihelia zic-zac* (Tenison-Woods) as occurring in the Glauconitic Limestone north of Blanche Point.

BRACHIOPODA: *Terebratulina lenticularis* Tate, *Magellania tateana* (Tenison-Woods), *Victorithyris pectoralis* (Tate), *Victorithyris sufflata* (Tate), *Liothyrella tateana* (Tenison-Woods), *Aldingia furculifera* (Tate), etc.

LAMELLIBRANCHIA: *Notostrea tatei* (Suter), *Spondylus* sp., *Chlamys* sp., *Chlamys flindersi* (Tate), *Glycimeris* sp.

ECHINOIDEA: *Stereocidaris australiae* (Duncan), *Pseudechinus woodsii* (Laube), *Fibularia gregata* Tate, *Australanthus longianus* (Gregory), *Eupatagus* sp. (a).

Other fossils include worm tubes and lamellibranch shells and casts, gastropod casts, crinoid remains, echinoid spines and ostracodes.

Contacts—The transition from the underlying polyzoal limestone to this bed has already been discussed. Marls which are highly glauconitic at the base overlie the Glauconitic Limestone and there is once again some evidence of a transition between these two formations. Due to erosive agents, since the overlying marls are very much softer, the limestone protrudes from below them and the contact is generally well shown.

Thickness—3 feet (maximum).

Formation 4: Blanche Point Marls

Member 4A: Blanche Point Transitional Marls

Exposure—From about 150 yards north of "Uncle Tom's Cabin" along Maslin Beach in the south-east corner of the bay to the north side of Blanche Point. Whilst this member reaches almost to Blanche Point along the northern side, it is no longer exposed south of the Point. It has been eroded away above the reef just north and east of Blanche Point to form a large shallow cutting beneath the overlying banded marls (Member 4B).

Lithology—This is essentially a marly bed, dark grey at the base due to the numerous glauconitic grains, becoming lighter in color higher up, although still retaining a speckled appearance. An analysis of a sample from the middle parts of this formation revealed that the bed here contains 80% $CaCO_3$ with some insolubles, including quartz, Fe_2O_3 and clay. On petrological considerations, the sample would be classed as a limey marl, but this is not entirely satisfactory because this formation is rich throughout in microfossils which have calcareous tests. As mentioned above, the composition varies from the base which is comparatively rich in macrofossils and predominantly glauconitic to the upper richly calcareous parts, but it is considered that the formation may be called a marl.

Fauna—The fauna includes the foraminifera *Uvigerina, Angulogerina, Anomalina, Astrononion, Nonion, Gyroidina, Discorbis, Pullenia, Siphonina, Notorotalia, Bulimina, Gümbelina, Bolivina, Bolivinopsis, Bolivinita,* and others (A105, A105a, A209).

It is from the base of this formation that *Hantkenina alabamensis* Cushman was taken by Parr.

Brachiopoda: *Victorithyris pectoralis* (Tate), *?V. sufflata* (Tate), *Terebratella (?) pentagonalis* (Tate), *Aldingia* sp. and others.

Lamellibranchia: *Notostrea tatei* (Suter), *Notostrea lubra* Finlay.

Other Fossils include a small Gastropod, Polyzoa, sponge spicules and Ostracodes.

Contacts—The glauconite-rich basal beds and the fact that macrofossils similar to those in the underlying bed occur also towards the base supply evidence of a transition between the underlying Glauconitic Limestone and this Marl. This contact reaches the base of the Pliocene as is to be seen in a small stream-course about 150 yards north of "Uncle Tom's Cabin." Overlying this Transitional Marl Member is the first hard band of the Blanche Point Banded Marls.

Thickness—The maximum thickness, by measurement, is 7½ feet.

Remarks—In view of Parr's discovery of *Hantkenina* the basal part of this formation must be assigned to the Upper Eocene.

Sample A105 was taken from the base and A105 (a) from 4 feet above the base in the vicinity of a fence which follows down over ?Pleistocene and Pliocene beds along the eastern limits of Maslin Bay, i.e., approximately 250 feet south of "Uncle Tom's Cabin." Sample A209 was collected from the base of the formation just west of the small shallow cave in the south-east corner of Maslin Bay.

Member 4B: Blanche Point Banded Marls

Exposure—From between "Uncle Tom's Cabin" and the fence just mentioned, where the base of the first hard band meets the base of the Pliocene, to just south of Blanche Point where the upper of the series of hard bands passes below sea-level. At this latter position the steep nature of the cliff-

faces common throughout almost the entire distance of exposure of this formation along the coastline is lost and from here south to Chinaman's Gully, a change in the nature of the coastline is noted.

Lithology—

(5)	Top: Soft clayey marls similar to the overlying Member 4C with hard grey nodular bands three inches thick at heights of ¾, 3, 3¾ and 5¼ feet above the base. The dip of the banded marls was determined by Lahee's method (1931) using the top of the band at 3¾ feet - - - - - -	5½ feet
(4)	Grey marls with three hard bands at heights of 2, 4 and 5½ feet above the base. Intervening softer bands are similar to the hard bands in composition but are not as consolidated -	6 feet
(3)	Soft yellow-grey marls with four hard grey nodular bands and capped by a 1-foot thick band of hard grey marl. Besides *Turritella aldingae* Tate which is abundant throughout the formation, these beds are rich in Polyzoa - - -	8 feet
(2)	Rubbly marls generally light grey in colour with irregular hard and some thin and nodular grey bands - - - -	12 feet
(1)	Greenish-grey and light grey marls, alike in appearance to the underlying Transitional Marls with a hard grey nodular band 2 feet up from the base and a hard light grey band 1 foot thick at the base - - - - - - -	5½ feet
	Total thickness -	37 feet

A chemical analysis revealed that the $CaCO_3$ content is 40% in the hard marls in bed (4). The examination of insoluble residues revealed a large percentage of silica. This was expected since microscopic examination of similar beds had shown relatively large numbers of sponge spicules. A thin section of Sample No. A1 revealed a green mineral (? glauconite) as occasional grains and forming a part of the matrix. Fissures developed in these beds have a north-south trend and may be lines of weakness culminating in the minor faulting seen almost due south in the Port Willunga Beds.

Fauna—

FORAMINIFERA are common but have not yet been fully studied.

BRACHIOPODA occur in sample A3.

CORALS: *Flabellum distinctum* Edwards and Haime. Tate (1878) also records *Amphihelia striata* Tenison-Woods from limestone bands in clays at Blanche Point.

LAMELLIBRANCHIA: ? *Notostrea tatei* (Suter), *Spondylus* sp., *Notostrea lubra* Finlay (not *in situ* but believed to be from the basal beds), *Propeamussium atkinsoni* (Johnston), *Chione multilamellata* Tate. Tate records from "Turritella Limestone bands Blanche Point": *Spondylus gaederopoides* McCoy, *Limopsis multiradiata* Tate, *Barbatia dissimilis* Tate.

GASTROPODA: *Tenagodes adelaidensis* (?), *Lyria* (?) sp., *Turritella aldingae* Tate, *Vermicularia* sp., *Siliquaria* sp., *Trivia avellanoides* McCoy.
Tate records from "Turritella bands, Blanche Point": *Epitonium lampra* (Tate).

SCAPHOPODA: *Dentalium* sp.

CEPHALOPODA: *Nautilus* sp.

OTHER FOSSILS include crinoid stems, sponge spicules, echinoid spines and octracodes. Sponge spicules are notably plentiful in the uppermost parts of this formation. An otolith was collected from bed (5), Sample A106 (d).

and other fish remains include shark's teeth and fish vertebrae. Large worm burrows have been noted in harder bands lower in the formation.

Additional fossils described by Tate and others are found in works listed in Singleton's comprehensive paper of 1941.

Contacts—The formation is underlain by the Blanche Point Transitional Marls and overlain conformably by the Blanche Point Soft Marls, Member 4C. The upper contact joins the base of the Pliocene almost directly above the small shallow cave in the south-east corner of Maslin Bay.

Thickness—37 feet.

Member 4C: Blanche Point Soft Marls

Exposure—The base of this formation meets the base of the Pliocene above and approximately 100 feet west of the small shallow cave in the south-east corner of Maslin Bay. The top of the formation meets the Pliocene approximately 400 yards north of Chinaman's Gully and this may be seen in a stream-course exposure. The top of the Marls is last observed just to the north of Aldinga Creek where it is decidedly blackish in color and passes down below sea-level. This however is only to be seen when there is little or no sand cover.

Lithology—This is essentially a brownish to greenish-grey marl, generally soft and clayey (more so towards the base), with some hard grey nodules dispersed irregularly throughout. There is a hard grey-black band which forms a reef due west of Chinaman's Gully at a height of approximately 45 feet and a thin nodular band 1¼ feet from the base. The uppermost bed is a dark greenish-grey colour and fossiliferous, being rich in *Limopsis chapmani* Singleton and *Turritella aldingae* Tate, the latter, however, being common throughout the formation.

A sample from the topmost *Limopsis* bed, A107 (c), was examined for foraminifera which were found to be very small and not numerous. The bed is extremely rich in glauconite which occurs as green pellets. Another characteristic feature of the upper beds of this formation are the white marly nodules which are sometimes of quite large dimensions. They appear to be non-fossiliferous and may possibly represent the relics of an erosional surface which existed prior to the deposition of the overlying non-marine sediments. The Blanche Point Marls are generally grey in colour throughout, some horizons being darker than others and this may be due partly to the presence of organic matter.

Analysis of Sample No. A107 revealed 47·5% $CaCO_3$, together with clay and some silica which were left as insolubles.

Fauna—

FORAMINIFERA: *Bulimina, Gümbelina, Bolivina, Uvigerina, Angulogerina, Anomalina, Astrononion, Gyroidina, Discorbis, Pullenia, Sphaeroidina* and others.

BRACHIOPODA: *Victorithyris sufflata* (Tate) and others.

LAMELLIBRANCHIA: *Limopsis chapmani* Singleton, *Dimya sigillata, Lentipecten* sp., *Lentipecten* cf. *victoriensis* Crespin, *Propeamussium atkinsoni* (Johnston), *Anomia* cf. *cymbula* Tate, *Cardium* sp., *Chione cainozoica* Tenison-Woods, *Arca equidens* Tate, *Chione multilamellata* Tate, and others.

GASTROPODA: *Turritella* sp., *Turritella aldingae* Tate, "*Murex*" sp., *Ancilla ligata* Tate, *Natica* sp., *Voluta pagodoides* Tate, *Trivia avellanoides* McCoy and *Vermicularia* sp.

SCAPHOPODA: *Dentalium* sp.

OTHER FOSSILS include sponge spicules and ostracodes.

Thickness—57 feet.

Contacts—The base of the formation is underlain by the topmost hard band of the alternate hard and soft bands of marl which form Member 4 B, whilst immediately above are the basal beds of the second non-marine beds, *i.e.,* laminated green, brown and yellow clays with white nodules.

FORMATION 5: CHINAMAN'S GULLY BEDS
(Second Non-Marine Formation)

Exposure—These beds meet the base of the Pliocene north of Chinaman's Gully, the base at a distance of 370 yards, the top at approximately 290 yards, but except where exposed in stream courses, they are generally obscured by Recent deposits in this vicinity. The best exposure is in Chinaman's Gully, whilst they are also well shown in two small stream cuttings just to the north. They are generally to be seen in part from Chinaman's Gully to Aldinga Creek but not south of the latter locality.

Lithology—Because these beds are easily measured and have some variation in composition they have been listed hereunder in tabulated form with sample numbers and thicknesses.

Lithology	Sample No.	Thickness
Top		
Yellow to brown becoming red laminated clayey to gritty bed, limonitic in part and containing nodules of blue-grey and green sandy clays which show Liesegang rings—this bed is in parts cross-bedded - - - - - - - - - -	A111	11″
Blue-grey silt with parallel bands of coarser sands	A110	8″
Red laminated sandy to clayey bed Thin band of bluish-grey silt Yellow laminated sandy bed Greenish-yellow silt band	A110	1′8″
Interbedded coarse and very fine to medium sands varying in colour from greenish-yellow to white and blue-grey with a hard white sandstone leaf at the base and some white sandy nodules just above the base. - - - - - - - - - -	A109	1′1″
Laminated green, brown and yellow clays with white sandy nodules.	A108	1′0″
Base - - - - - - - - - -		5′4″

In samples of the coarser constituents examined, quartz was seen to be the predominant mineral but there were other dark grains and some muscovite. Clay, sometimes with iron oxides, and silt form the very fine constituents of these beds.

Fauna—Some foraminiferal tests were obtained from sample No. A109, but these are thought to have been derived from the underlying soft marls as remanié fossils during erosion under a terrestrial environment.

Contacts—This bed overlies the Blanche Point Soft Marls and, at the base, shows a marked contrast to the highly fossiliferous grey marls which have fairly abundant white nodules at the upper limits. A green bed with a maximum thick-

ness of 1½ feet overlies the formation, and whilst the break as shown by the change in colour is quite evident, the microfossil assemblage, as discussed under Formation 6, indicates a distinct change in the environment.

Thickness—By measurement, 5½ feet maximum.

FORMATION 6: PORT WILLUNGA BEDS

Exposure—The northernmost limit of this formation is somewhat obscured by Recent terrestrial and aeolian deposits. The top of the lowest member of the formation meets the Pliocene basal unconformity approximately 270 yards north of Chinaman's Gully. This is exposed in the bed of a small stream-course and by estimation, taking into consideration the apparent dip of the beds (approximately 1½° or 120 feet/mile 200° true) and of the unconformity (approximately 0° in the vicinity) the northernmost limit is 280 to 290 yards north of Chinaman's Gully. The southernmost limit occurs where the base of the Pliocene dips below the sand at an approximate distance of 1,000 yards south of the remaining jetty piles at Port Willunga. This distance is based on the level of the beach sand during February, 1951, and will be subject to variation.

Lithology—Due to the variable nature of the members of the formation, a column had to be drawn (Fig. 2), showing such variation, sample horizons and thicknesses. The minor faulting discussed earlier, the thinning of certain beds, cross-bedding and the effects of a relatively deeper Aldinga Creek in post-Pleistocene times have all created some difficulties in the correlation of beds and measurements of thickness. The formation as a lithological unit could be classed as an arenaceous polyzoal limestone with argillaceous bands.

Fauna—

FORAMINIFERA: Sample No. A112, a distinctive assemblage of arenaceous types which have not been identified.
A113: *Anomalina, Sherbornina, Sphaeroidina* and others.
A114: *Verneuilina* (?), *Gumbelina, Bolivina, Uvigerina, Angulogerina, Astrononion, Gyroidina, Nonion, Discorbis, Planorbulina, Sherbornina, Sphaeroidina* and others.

CORALS: *Graphularia senescens* Tate.

POLYZOA: *Cellepora* cf. *verruculata*.

BRACHIOPODA: *Magellania garibaldiana* (Davidson); *Stethothyris* (?) *insolita* (Tate), ? *Magellania tateana* (Tenison-Woods), *Victorithyris sufflata* (Tate), and others.

LAMELLIBRANCHIA: *"Pecten"* cf. *consobrinus* Tate, *"P." eyrei* Tate, *Ostrea arenicola* Tate, *Chlamys asperrimus asperrimus* (Lamarck), *Pinna* sp. *Dimya dissimilis* Tate.

GASTROPODA: *Vermicularia* sp., *Turritella* sp., ? *Mitra* sp., *Cirsotrema mariae* (Tate).

ECHINOIDEA: *Duncaniaster australiae* (Duncan), *Nucleolites* sp., *Linthia compressa* (Duncan), *Pseudechinus woodsii* (*Laube*), *Eupatagus* sp., *Stereocidaris australiae* (Duncan), *Prionocidaris scoparia* Chapman and Cudmore, *Scutellina patella* Tate, *Fibularia gregata* Tate, *Goniocidaris prunispinosa* Chapman and Cudmore.

ASTEROIDEA: *Pentagonaster* sp.

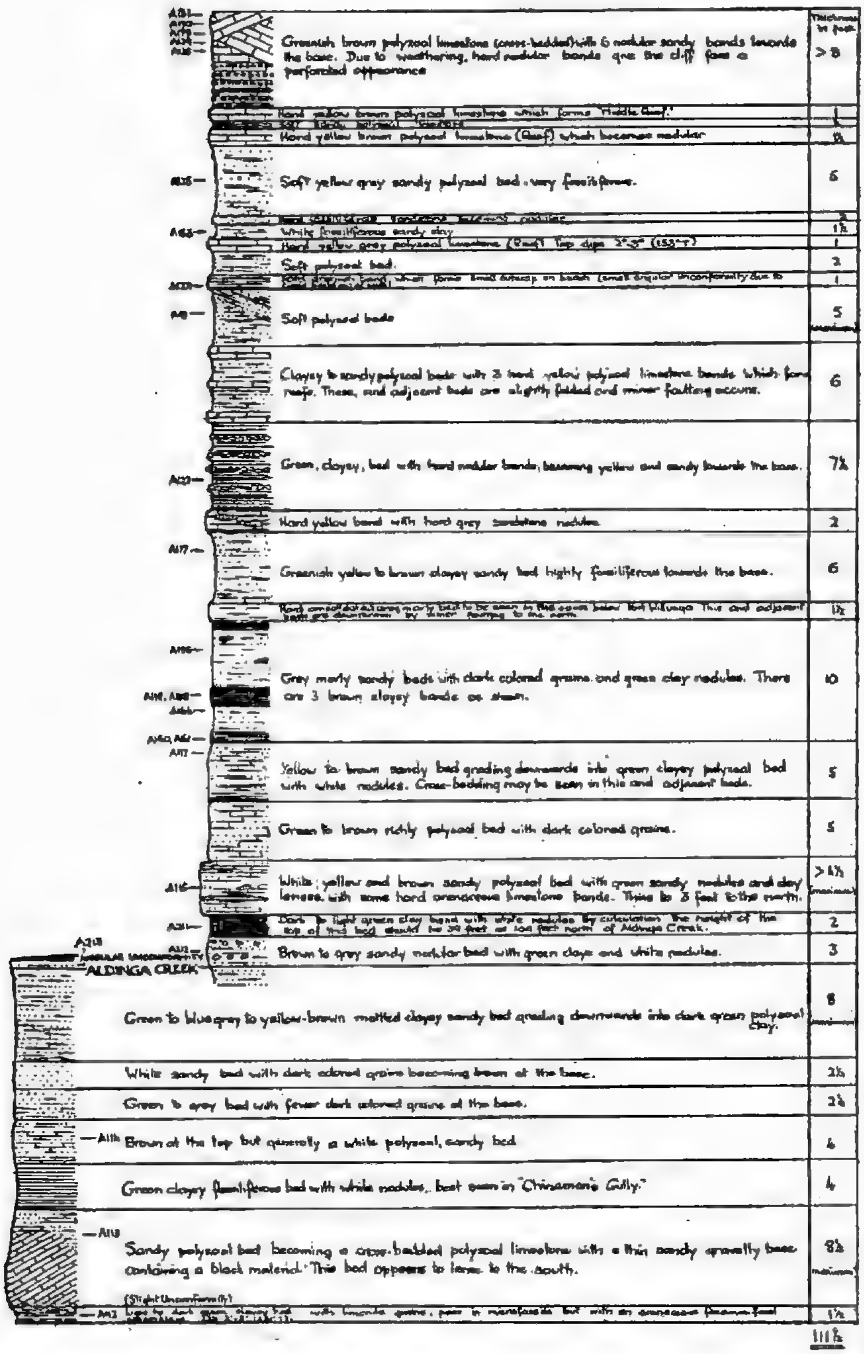
CRUSTACEA: abundant Cirripedia.

PISCES: Tooth of *Odontaspis contortidens* Agassiz, teeth of *Odontaspis attenuata* Davis.

OTHER FOSSILS include worm tubes (A151), and microfossil samples contain Polyzoa, Ostracodes, sponge spicules, echinoid spines, crinoid stem remains.

Hereunder are some additional fossils mentioned by Tate in various publications:

FIG. 2 THE PORT WILLUNGA BEDS.



BRACHIOPODA: *Magellania furcata* (Tate)—"rather rare in the Polyzoal calciferous sands forming the lower part of the seacliffs immediately south of Port Willunga Jetty"; *Victorithyris sufflata* (Tate)—same locality; *Magasella woodsiana* Tate—"yellow calciferous sands, Aldinga Bay."

LAMELLIBRANCHIA: *"Pecten" peroni* Tate "polyzoal limestone, Aldinga Bay."
ECHINOIDEA: *Eupatagus decipiens* Tate—"calciferous sandstone, south side Port Willunga Jetty," *Lovenia forbesi* Tenison-Woods—"calciferous sandstone, Eocene, Aldinga." Tate and Dennant (1896) list also *Maretia anomola* Duncan and the Crinoid *Antedon* sp., from "calciferous sand rock with hard concreted portons at top and siliceous bands at bottom," Port Willunga Jetty, Lower Beds. The reader is also referred to a paper by Miss Crespin (1946) for a list of microfossils, mainly Foraminifera and Polyzoa, which come from her Samples Nos. 1 to 4.

Contacts—The formation is underlain by the second non-marine formation as described under Formation 5. The top of the Port Willunga Beds is not revealed in this succession.

Thickness—by measure 111½ feet.

FORMATION 7: PLIOCENE LIMESTONES

Exposure—Sands and limestones with sands all regarded as Pliocene in age extend continuously from north of Ochre Point to south of Snapper Point.

Lithology—This formation consists predominantly of white and yellow sands and arenaceous limestones with occasional lenses of clayey sands. For the purpose of this discussion, the Pliocene formation will be considered in three divisions numbered 1 to 3.

1. From the north of this succession to 120 yards south of the spur below the trig. point, the formation consists mainly of unfossiliferous yellow and white sands. A typical section of these beds may be seen at the sand quarry where a basal white, brown, yellow and red mottled friable sandstone band is overlain by white and yellow sands showing some banding. (Sample A186). In the upper parts of this section there is a yellow, hard limonitic (in part) sandy band, the thickness of the formation being 10½ feet. The only fossiliferous arenaceous limestone occurring in this division of the succession is a capping over the small hill between the Canyon and Bennett's Creek. This bed is hard, white with some yellow staining and travertinous in appearance (Sample A175). It is slightly fossiliferous, 4 feet thick and overlying 6 feet of yellow sands (Sample A176).

2. This division extends from 120 yards south of the spur below the trig. point to the north side of Blanche Point. A typical section is described from above "Uncle Tom's Cabin": yellow sands (Sample A200) 9 feet thick are overlain by a green clayey sandy bed (A199c) grading into a dark grey, green to brown clay (A199b) 4½ feet thick, capped by white sandy limestone (A199a) 5½ feet thick. This upper limestone is slightly fossiliferous, and towards the north of this division it is slightly pebbly; the underlying 12 feet of sands in this position also contain pebbly bands.

The top of the upper hard limestone forms an intermediate platform between beach level and the top of the cliffs. This hard band, however, does not seem to extend to the base of the ? Pleistocene clays in the northern parts of this division, where grey to white pebbly sands (Sample A197) pass upwards into yellow sandy clays (A196) and yellow clays (A195). The transition is exposed in a small stream course, and the clays here pass directly upwards into a grey mottled bed (A194) which grades up into red ? Pleistocene beds. The formation as described (*i.e.*, above "Uncle Tom's Cabin") is the same in the southern limits of this division. There are, however, calcareous nodules in the basal parts here, which are similar in appearance to some which occur at the base of the Pliocene along the north side of Blanche Point. A feature of interest is the so-called "sandstone dyke" which occurs on the path from "Uncle Tom's Cabin" to the top of the ? Pleistocene. This is a "dyke" in appearance only, formed by the lower sands

of the formation which have filled in a crack in the underlying Pre-Pliocene beds and become cemented to form a sandstone.

3. The third division may be seen from Blanche Point to south of Snapper Point almost to the huts at Aldinga Beach. Generally the beds are as follows: Basal beds of highly fossiliferous yellow sands overlain by white sands with irregular bands and lenses of calcareous sandstone and arenaceous limestone are capped by 5 feet of white to grey arenaceous limestone with sandy lenses, the whole being approximately 18 to 20 feet thick. The section is generally fossiliferous, more so at the base and in the irregular bands where mostly casts only are to be found. Some fossils are to be found in the white sands and fossil impressions and casts are to be seen with some occasional fossils in the upper hard white limestone. In places a greenish sandy clayey bed, best seen in Chinaman's Gully, underlies this upper hard white limestone and there is evidence to suggest that there is an unconformity below this latter bed. A typical section may be seen along the road leading to the jetty at Port Willunga, and this is described hereunder:

Top	
White fossiliferous arenaceous limestone	5′0″
Yellow to white mottled sand	2′0″
Hard calcareous sandstone with some fossils	1′8″
White sand	1′0″
Hard calcareous sandstone with fossils	1′0″
White sand	1′0″
Hard arenaceous richly fossiliferous limestone	2′0″
White fossiliferous sand	9″
Yellow sand with hard sandstone leaf	2″
White sand	8″
Hard arenaceous fossiliferous limestone	1′6″
Yellow to white mottled sands, richly fossiliferous	9″
Hard fossiliferous nodular limestone	6″
	18′0″

Boulders of Pre-Pliocene formations are occasionally found at the base of the Pliocene beds and white chalky nodules are also found in the coloured beds immediately underlying the topmost arenaceous limestone. The top of this formation is exposed between Snapper Point and the huts at Aldinga Bay as a fossil erosion surface.

Fauna—

FORAMINIFERA: *Elphidium* species are prominent but have not been separated. *Marginopora vertebralis* Quoy and Gaimard is common in the hard limestone bands. (Samples A163, A165).

LAMELLIBRANCHIA: *Ostrea arenicola* Tate, *Spondylus spondyloides* (Tate), *"Pecten" consobrinus* Tate, *Chlamys asperrimus antiaustralis* (Tate), *Tellina lata* Quoy and Gaimard, *Dosinia* (*Kereia*) *greyi* Zittel, *Pinna* sp. (b), *Spisula variabilis* (Tate).

Tate lists these additional species: *Placunanomia ione* Gray, *"Pecten" palmipes* Tate, *Amussium lucens* Tate, *Pinna semicostata* Tate, *Glycimeris convexus* Tate ("imperfect specimens"), *Trigonia acuticostata* McCoy ("casts probably of this species"), *Cardita trigonalis* Tate, *Lucina araea* Tate, *L. nuciformis* Tate, *L. fabuloides* Tate, *Loripes simulans* Tate, *Lepton planiusculum* Tate, *Cucullaea corioensis* McCoy, *Crassatella oblonga* (Tenison-Woods), *Pecten subbifrons* Tate, *Limatula jeffreysiana* (Tate), *Meretrix sphericula* Basedow ("large imperfect cast referable to this species").

GASTROPODA: Casts of *Potamides* sp., *Cerithium* sp., *Phasianella* sp., *Terebra* sp., *Cassis* sp., ? *Architectonica* sp., *Bulinella* sp., and casts and external moulds of *Haliotis* sp. have been seen.

Tate lists these additional fossils: *Trophon anceps* Tate, *Lampusia sexcostata* Tate, *Cominella subfilicea* Tate, *Latirus approximans* (Tate), *Ancilla orycta* Tate, *Terebra mitrellaeformis* Tate, *Terebra crassa* Tate, casts of *Cassis textilis* Tate, *Natica subvarians* Tate, *Capulus danieli* Crosse, *Rhinoclavis subcalvatus* (Tate), and the SCAPHOPOD *Cadulus acuminatus* Deshayes.

ECHINOIDEAS *Peronella platymodes* (Tate), and others.

CRUSTACEA: Ostracodes, crab claws.

Whilst casts of fossils are common in the lower beds of the formation, shells are also plentiful and, in particular, *Ostrea arenicola*, *Spondylus spondyloides*, "*Pecten*" *consobrinus*, and *Chlamys asperrimus antiaustralis* are abundant. These beds are sometimes referred to as "Oyster Banks".

Contacts—The formation overlies the Pre-Pliocene formations with angular unconformity and is overlain by the ? Pleistocene beds. Where the ? Pleistocene beds directly overlie sands, the upper contact is not always well defined.

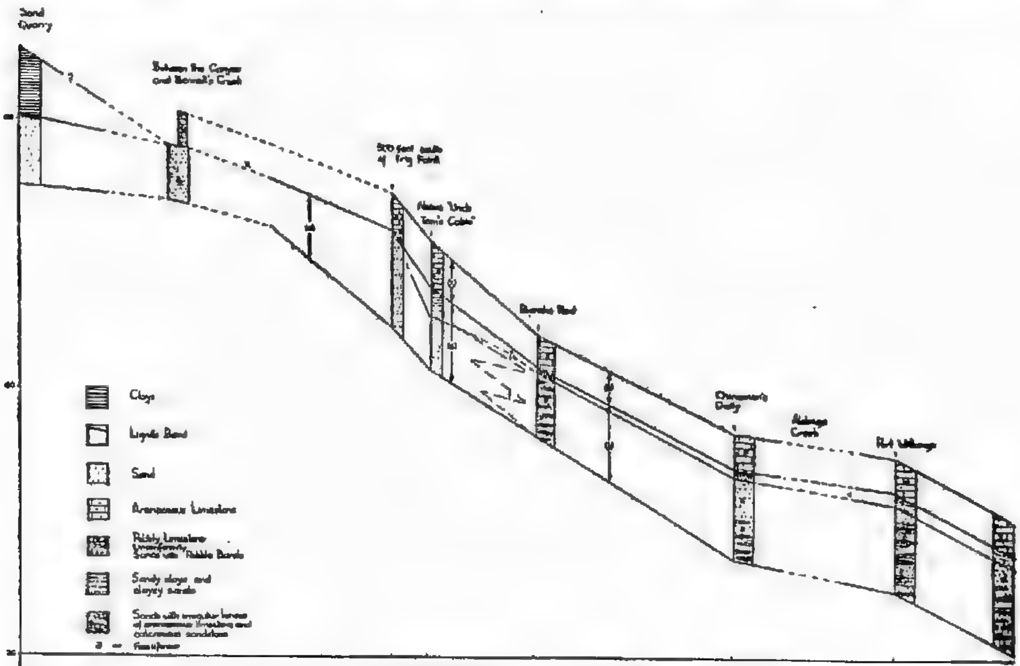


FIG 3 : THE CORRELATION OF THE PLIOCENE BEDS

Thickness—The maximum thickness by measurement varies from 18 to 20 feet.

Remarks—This formation could possibly be divided into three members, viz: (a) Non-marine Sands, (b) First Marine Beds and (c) Second Marine Limestone, (see Fig. 3). The subdivision is based on these facts:

(a) the sands from north of Ochre Point to north of Blanche Point are unfossiliferous, they are capped by limonite (? lateritic) to the north and just below the trig point they have pebble and gravel bands. Such properties suggest a terrestrial environment. In addtion to these may be quoted the occurrence of a silty bed containing lignitic material at the top of Pliocene sands at the sand quarry. It underlies a brown limonitic bed and dark brown-green clays which may be Pliocene or ?Pleistocene in age, and overlies a con-

solidated sandy bed highly perforated by roots. In view of available facts, *i.e.*, the limonitic capping to these sands further south, the clay occurring above the sands above "Uncle Tom's Cabin" and pieces of wood from this locality, the lignite band is tentatively classed as Pliocene.

(b) The first marine series includes the lower sands, sandstones and limestones described under Division 3. These are highly fossiliferous and in contrast to the non-marine beds described under (a) above. The sandy clayey bed at the top of these beds may possibly be equivalent to the clays at the top of the non-marine beds above "Uncle Tom's Cabin." Any transition from a non-marine to a marine environment will be exposed along the north side of Blanche Point but these beds are inaccessible.

(c) The upper limestone described under Divisions 2 and 3 (Lithology) appears to overlie the basal non-marine and marine sands with unconformity. It appears to be approximately uniform in lithological nature and, although assumptions can only be made in general on casts of fossils, the faunal assemblage seems to differ at least in part from the assemblage of the first marine beds. The outlier of Pliocene limestone occurring between Bennett's Creek and the Canyon is tentatively placed with this member. It has the same travertinous appearance and is poorly fossiliferous, casts only having been seen.

Unit No. 8: ? Pleistocene and Recent Deposits

The ?Pleistocene beds are exposed from north of Ochre Point to South of Snapper Point and consist predominantly of red mottled sandy clays overlain by green sandy clays. Boulder and gravel beds were noted in the red beds at Ochre Point but generally the composition of the beds is as described above. South of Blanche Point the lower red beds have been covered by the overlying green beds and are no longer visible. A thickness of 10 feet of brown to green clays underlies the red beds in the northern parts of the succession but it is not certain whether these beds belong to the Pliocene non-marine member or ? Pleistocene. The maximum thickness of ? Pleistocene beds as measured between the trig. point and "Uncle Tom's Cabin" is 59 feet, of which the red beds form 39 feet. From Blanche Point to Chinaman's Gully, these beds gradually become thinner but from Port Willunga to Snapper Point they again approach the maximum thickness, and at Snapper Point are approximately 55 feet thick. These beds cannot on available evidence be classed definitely as Pleistocene.

Angular unconformity between Pliocene and Pre-Pliocene beds may be seen from approximately one-third of a mile north of Blanche Point to just north of Snapper Point. It is also seen in the southermost quarry cutting where the contact between the white sands and the overlying brown and green sands is truncated by almost horizontal sands, the significance of which is discussed below. This unconformity dips from a height of approximately 90 feet in the vicinity of the sand quarry to sea level just north of Snapper Point, (i.e., approximately 30 feet per mile).

The Pliocene-?Pleistocene contact is well defined from Blanche Point to just north of the huts at Aldinga Beach where an erosion surface is exposed on the uppermost limestone of the Pliocene beds. North of Blanche Point, however, the upper limestone bed is not continuous and the base of the ?Pleistocene occurs directly above sands for most of the distance. Under such conditions the break between Pliocene and ?Pleistocene is not well defined and there appears to be an intermixing of the upper Pliocene sands with the basal beds of the ?Pleistocene deposits. This contact has a similar dip to the angular unconformity and from a height of approximately 100 feet to the north of the succession, it reaches sea level at Snapper Point as the erosion surface mentioned above.

Recent deposits include a thin layer of kunkar, which, in general, is continuous and overlying the ? Pleistocene beds. However, it does overlie other beds as mentioned hereunder in the discussion of the creeks. A thin layer of topsoil is seen in parts of the section, whilst also included under Recent deposits are the aeolian and other deposits which, particularly in the embayments, obscure some parts of the lower beds in the coastal section. The three creeks which traverse the coastal section at the Canyon, Bennett's Creek and Aldinga Creek are believed to have been much deeper at some time between the completion of deposition of the ? Pleistocene beds and Recent times. At the Canyon, in the northern wall, the ? Pleistocene beds are no longer divisible into two divisions and seem to have been reworked. The North and South Maslin sands exposed in the southern wall have likewise, in part, been resorted to form a bed of pebbles and coarse white sand overlain by a conglomeratic deposit with pebbles of limonite and quartzite in sand beds. This formation is in complete contrast to the exposure at the westernmost portions of the southern wall, where the North Maslin Sands are exposed beneath a thickness of approximately 30 feet of South Maslin sands in an unaltered condition. The northern wall shows only the resorted ? Pleistocene beds, and these are overlain by Recent sands which extend to the top of the small hill immediately north, where only small outliers of the kunkar remain above Pliocene and ? Pleistocene deposits. Silicified roots are to be seen in some abundance in these sands.

At Bennett's Creek the ? Pleistocene beds are not to be seen within 150 yards either north or south, and Recent sands and deposits form gradual inclinations on both sides. Just south of Bennett's Creek, the South Maslin sands have been cemented to form a hard rock at the surface. Just north and south of Aldinga Creek the old creek bed may be seen cutting the section. The overlying ? Pleistocene beds have been removed and the thin kunkar layer directly overlies both Pliocene and Pre-Pliocene beds, and in the south it may be seen resting above the fluvial deposits of the former creek. The Pre-Pliocene beds appear to fold downwards beneath these deposits, and this can be accounted for by a slumping of the upper incompetent beds when lower beds have collapsed due to erosional forces. An erosional surface, similar to the type seen south of Snapper Point, was observed just north of Port Willunga at beach level above the fluvial sediments, which are predominantly dark in colour and contain pebbles of kunkar which define bedding. Evidence of a submergence of the present coastline in comparatively Recent times may be seen in the form of terraces in the vicinity of Bennett's Creek. These consist of boulder and pebble beds which occur above the present beach level associated with deposits of Recent types of shells, including *Turbo undulata* Martyn and the common limpet *Cellana tramoserica* (Martyn). On the other hand, these may be storm beaches or such shell deposits may have been formed by wandering tribes of aboriginals who have been known to pass through this vicinity and who leave such remains at their squats. Definite emergence of the coastline, however, seems probable in view of the stream profiles earlier discussed. Certain terms such as "raised sea-beaches" have been purposely avoided in this discussion and definite conclusions regarding changes in sea-level have not been formed in view of the fact that it has not been possible to carry out detailed studies.

IV CONDITIONS OF DEPOSITION

The North Maslin sand deposit is probably deltaic and may have originated from adjacent Precambrian quartz-rich sediments. Gravel and coarse sediments are usually not common in deltaic deposits, except where streams flow into a sea or lake directly from uplands, when gravel may become a considerable part of

the sediments. Clay bands with and without plant remains and cross-laminations are also suggestive of deltaic deposits. The quartz boulders and pebbles at the base of the sands are probably derived from two sources, the more angular being from adjacent Precambrian uplands and left as relics of an original piedmont deposit, whilst highly polished pebbles have probably been accumulated by the resorting of the underlying ? Permian beds, the till being removed by distributaries to possibly form "bottomset"[2] beds. Determination of "subaerial" and "subaqueous", "topset" and "foreset" beds has not been possible in view of the relatively small size of this deposit as compared with the large areas usually covered by deltaic deposits, and because it has only been possible to examine this exposure more or less as a vertical section.

There is evidence to suggest that there is a transition between the non-marine sands and the overlying South Maslin sands. As already mentioned, there is a brown bed with quartz pebbles 3 feet above the base of the latter, and this is considered as being deposited by terrestrial agents. Twenhofel, in his discussion of "sediments of the foreset slope," says: "Certain chemical sediments, such as glauconite, may also form," and in view of the cross-bedding which is in part similar to that exhibited by the North Maslin sands, it is suggested that these beds are closely associated with the deltaic environment. The units formed in the brown sands are, however, generally more lenticular than those in the white sands. The cross-laminations of the South Maslin sands are produced mainly under a marine environment in contrast to those of the sand quarry deposit. It has already been proposed that some of the limonitic grains have been formed by the alteration of glauconite, but it is not within the scope of this paper to discuss the formation of the latter mineral. The limonitic bands exposed in cross-laminations are not regarded as of the same origin as the grains formed by alteration of glauconite. They form the capping to units in the lower parts of this formation, and are probably the result of precipitation of colloidal clay and iron oxide, ". . . . and there may also be much precipitation of colloids of iron oxide and silica where fresh and salt waters mingle" (Twenhofel, 1950). This would also explain their somewhat laminated nature. Mudcracks with the intervening limonite being sometimes curved concavely upwards or peculiarly coiled could be formed in this near-shore environment. Only some of the limonite grains can be acconted for by the alteration of glauconite and the remainder may be attributed to a precipitation from colloids, followed by dispersal amongst quartz sands by weak wave or current action. Iron oxides derived from the chocolate shales underlying the Precambrian quartzites, etc., at Ochre Cove, could be the source of much of this limonite. At the furthermost limits of this formation from the sand quarry, the sands are predominantly limonitic and the limonitic capping is no longer observed. The mingling of fresh and salt waters would be less marked at this distance from the landmass, and the percentage of grains formed from glauconite would be greater in deeper neritic seas. Macrofossils are found mainly in lenses of a light-green to purple colour, and these may be part of the "foreset" environment (Twenhofel states that "shell matter should be more or less abundant over foreset bottoms, particularly between distributary currents . . . .").

Erosion occurred before the next group of beds was formed, and a disconformity separates the South Maslin sands and the Tortachilla Limestones. The latter are richly fossiliferous and are rich at the base in limonite grains derived from the underlying formation, and polyzoa. The character of the fauna

[2] The terms used in this discussion of deltaic deposits and such statements as are made in support of a deltaic environment are taken from Twenhofel "Principles of Sedimentation" Second Edition, 1950, p. 102-118. Such terms and statements have been included in quotation marks.

which is mainly benthonic with some planktonic forms, is indicative of a shallow water environment. These are autochthonous limestones which generally have little or no clastic detritus and it is suggested that they were formed in clear water with little wave action. Above the less consolidated, limonitic, polyzoal sands they become very hard, although there are softer pockets of glauconitic clay in the upper parts. Sedentary organisms may have played a major part in the formation of these beds, in which case the limestones could be regarded as a biostrome formation. It would seem from the transition of the purely polyzoal limestone to glauconitic limestone that the latter can be formed gradually without materially changing environmental conditions. However, there must be the addition of material from which such glauconite can be formed, and in the absence of biotite flakes, in view of the composition of the directly overlying marls, it is contended that a certain amount of clay, probably in colloidal form, has been deposited at the same time as the upper parts of the biostrome were being formed.

As the amount of clay deposited became greater, a new sediment was formed, which was also quite rich in $CaCO_3$, a fair percentage of this being contributed by the tests of micro-organisms, mainly foraminifera. There is a transition, therefore, from the glauconitic limestone to a glauconitic and limey marl, the basal formation of the Blanche Point Marls. Above the transitional marls are hard and soft bands of calcareous, and in part siliceous sediments which are essentially marls in composition. Silica is contributed in the main by sponge spicules, which become comparatively abundant. The sponges which predominated are of the tetractinellid and monactinellid rather than hexactinellid type, and these are generally more common in shallow warmer waters. The tests of *Turritella aldingae* are plentiful in these and the overlying soft marls, and their abundance is marked in the upper banded marls, where they may be seen deposited at random. One would have expected a set pattern of arrangement for these tests had there been any distinct movement of water. Further evidence for suggesting calm waters is given by the flat nature of exposed surfaces as seen south of Blanche Point, and also by the discovery of paired Lamellibranch valves and an Echinoid with some spines still attached. There seems to be little change in the conditions of deposition from the earlier deposition of the Polyzoal limestone to the final stages of deposition of the Blanche Point Marls, the marine environmental conditions of relatively shallow clear waters, with little movement persisting throughout. Parr, as mentioned by Glaessner (1951) found that "all the beds at Port Willunga and Maslin Bay were laid down in much shallower water than the Brown's Creek and Hamilton Creek beds. . . . In all of the samples I have looked at there is an almost complete absence of pelagic forms and species of the Polymorphinidae are very common." However, the height of sea-level relative to the base level of deposition may have changed during the deposition of the *Limopsis* bed at the top of the Soft Marls. Here foraminifera are not abundant and are relatively very small, whilst large numbers of *Limopsis* are found with *Chione*, some *Turritella* and other mollusca, the pellets of such being abundant. This distinctive biofacies found only in this horizon is thought to represent a different environment.

Following the marine phase, there are beds which have been deposited under a terrestrial environment. An erosion surface may have existed as previously explained by the presence of white nodules at the top of the marls and the second non-marine series is generally unfossiliferous, such fossils as are found being few in number and probably derived from the underlying formation, *i.e.*, remanié fossils. This formation, the Chinaman's Gully Beds, is variously coloured from grey-blue silts to red and brown clayey gritty beds, it is in part cross-bedded and shows Liesegang rings. These deposits also resemble a small deltaic deposit formed

under arid conditions. This formation is only 5 feet thick and overlain by the Port Willunga Beds. The base of these latter beds consists of a green bed $1\frac{1}{2}$ feet thick, rich in arenaceous foraminifera and with some limonitic grains. The faunal assemblage is peculiar and may possibly represent a brackish water facies. The environment thereafter is again marine, and, whilst the faunal assemblage and the nature of the sediments indicate shallow water conditions, there is evidence to suggest that these deposits were more affected by wave and current action, due to the fact that the tops of beds seem to be frequently levelled by erosion. Cross-bedding is common, polyzoal remains being commonly prominent in cross-bedded sediments. Foraminifera are mainly shallow water types, and some appear to be adapted to attachment, being characterised by flat or concave surfaces.

The beds described above belong to the Pre-Pliocene formations and have a slight dip generally less than 3° in directions which although variable are, with the exception of the base of the North Maslin Sands, confined to a south-west to south-east direction. These beds, originally horizontal, have been tilted by the tectonic movements of late Miocene age.

Pliocene beds have been discussed in some detail, and the conditions of deposition with reasons for the assumptions made are mentioned under Formation 7. Shallow seas formed part of this succession at least as far north as the Canyon towards the end of the Tertiary period. The ? Pleistocene beds are widespread, and whilst they have been obviously deposited under a terrestrial environment, little more can be said concerning conditions of deposition until they have been studied in more detail.

V STRATIGRAPHIC REMARKS

1. *Ranges of Fossils.* Some detailed work has been commenced in the study of the Foraminifera from various horizons and some macrofossils have been named, and their ranges throughout the succession noted, but it will not be possible to draw any conclusions until more work has been done. *Hantkenina alabamensis* and the significance of its discovery in the basal beds of the Blanche Point North Transitional Marls has already been discussed. *Sherbornina* is confined to the limits of the Port Willunga Beds. Certain macrofossils have ranges which appear to be restricted and some of these have been listed in Table II.

Fossils not listed in the table but which may prove to be important include: (1) *Notostrea lubra,* which has been found mainly in fallen blocks, but is probably restricted to the Blanche Point Transitional Marls and the basal members of the overlying Banded Marls: (2) *Aturia,* which was found by Dr. Glaessner three feet above the base of the South Maslin Polyzoal Limestone and has not been found elsewhere; *Nautilus* remains seem to be common in the Banded Marls; (3) *Marginopora vertebralis* is found in the marine Pliocene beds, more so in the upper limestone, member (c). An occurrence of interest is in the cross-bedded Polyzoal limestone at the base of the Port Willunga Beds, sample No. A113, where there is an abundance of barnacle remains, which do not appear elsewhere in the succession.

2. *Sequence of Strata.* The "Glauconitic Marls with *Hantkenina*" (Glaessner 1951)' are equivalent to my Blanche Point Transitional Marls, and the beds which underlie this Member are not younger than Upper Eocene.

Although the North Maslin Sands are a non-marine formation there is evidence of a transition between them and the overlying South Maslin Sands. Since these latter beds appear to have been eroded before deposition of the overlying Tortachilla Limestones, it is suggested that the South Maslin Sands are to be regarded as Lower Eocene, the North Maslin Sands as basal Tertiary, and

the Tortachilla Limestones which pass with transition upwards into the Blanche Point Transitional Marls are probably Middle to Upper Eocene in age. Conformably above the Transitional Marls are the Blanche Point Banded Marls ("Turritella Marls," Glaessner 1951) and the Blanche Point Soft Marls ("Turritella Clays of Aldinga Bay").

TABLE II

Fossils	Formation	3		4			6	7	
	Members	A	B	A	B	C		B	C
Echinolampas posterocrassus		x							
Australanthus longianus		x	x						
Eupatagus sp.		x	x						
Chlamys flindersi			x	x	?				
Notostrea tatei			x						
Spondylus sp.					x				
Turritella aldingae					x	x			
Flabellum distinctum					x				
Lentipecten sp.						x			
Lentipecten cf. *victoriensis*						x			
Propeamussium atkinsoni					x	x			
Limopsis chapmani						x			
Ancilla ligata						x			
Voluta pagodoides						x			
Trivia avellanoides					x	x			
"Pecten" eyrei							x		
"Pecten" cf. *consobrinus*							x		
Chlamys asperrimus asperrimus							x		
Ostrea arenicola							x	x	
Duncaniaster australiae							x		
Linthia compressa							x		
Graphularia senescens							x		
Spondylus spondyloides								x	
"Pecten" consobrinus								x	
Chlamys asperrimus antiaustralis								x	
Spisula variabilis								?	x
Peronella platymodes								x	

Glaessner (1951) suggests that the age of these beds is Oligocene. In view of the conformable nature of these Formations, this suggestion seems to be justified and it will be possible to verify it as foraminiferal research proceeds. The Chinaman's Gully Beds ("Red Sands") have been mentioned as possibly overlying an erosional surface, and because there appears to be a transition between them and the overlying Port Willunga Beds ("Polyzoal Beds of Aldinga Bay"), it is suggested that they should be regarded as closer to the latter than to the underlying Marls.

The Pliocene Limestones ("Upper Aldingan") lie with angular unconformity over the formations discussed. Glaessner places these limestones with the "Upper Murravian" in the Lower Pliocene (Kalimnan). Whether its tentative local subdivision outlined above is justified will remain uncertain until the outcrops have been studied in greater detail. Likewise, the age of the ? Pleistocene and Recent deposits will remain in doubt until further research has been carried out.

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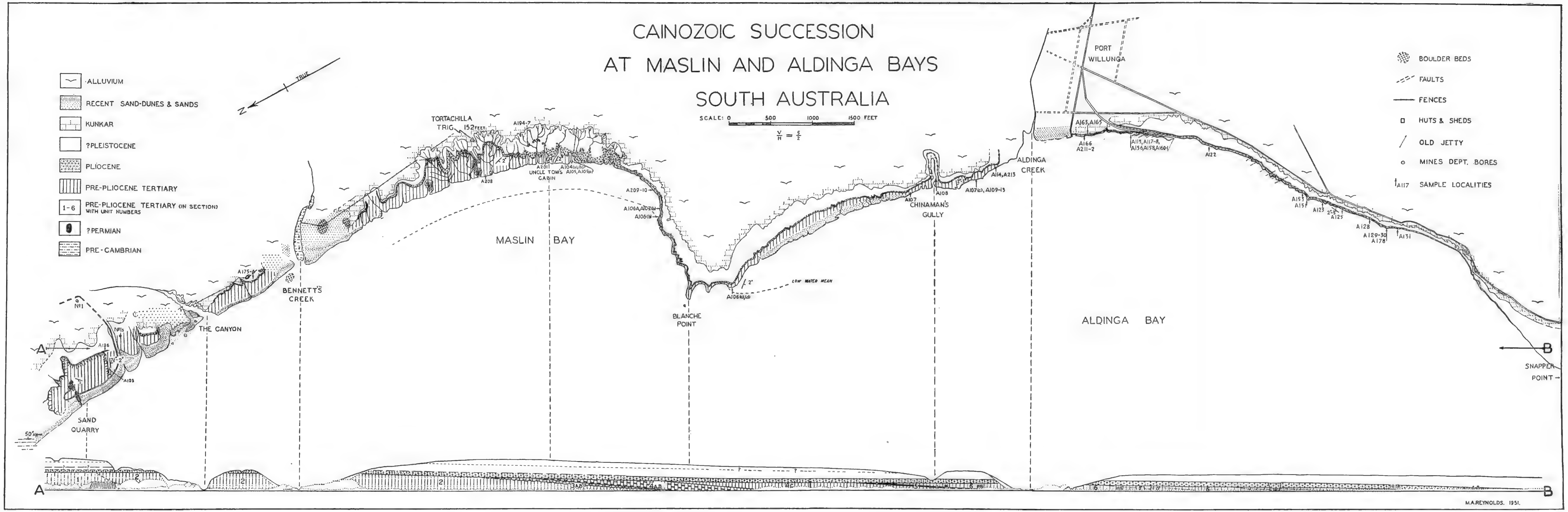

CAINOZOIC SUCCESSION
AT MASLIN AND ALDINGA BAYS
SOUTH AUSTRALIA
SCALE: 0 500 1000 1500 FEET
ALLUVIUM
RECENT SAND-DUNES & SANDS
KUNKAR
?PLEISTOCENE
PLIOCENE
PRE-PLIOCENE TERTIARY
1-6 PRE-PLIOCENE TERTIARY (IN SECTION) WITH UNIT NUMBERS
?PERMIAN
PRE-CAMBRIAN
BOULDER BEDS
FAULTS
FENCES
HUTS & SHEDS
OLD JETTY
MINES DEPT. BORES
A117 SAMPLE LOCALITIES
TRUE N
TORTACHILLA TRIG. 152 FEET
UNCLE TOM'S CABIN
MASLIN BAY
BENNETT'S CREEK
THE CANYON
SAND QUARRY
BLANCHE POINT
LOW WATER MEAN
CHINAMAN'S GULLY
ALDINGA CREEK
PORT WILLUNGA
ALDINGA BAY
SNAPPER POINT
A
B
M.A.REYNOLDS. 1951.

CONDITIONS OF TERTIARY SEDIMENTATION IN SOUTHERN AUSTRALIA

BY MARTIN F. GLAESSNER

Summary

Tertiary sedimentation in southern Australia begins generally with paralic deposits (brackish, lignitiferous, intermittently marine), followed in some areas by an Upper Eocene marine ingression. This is widespread in South Australia, possibly extending to Western Australia, but limited in Victoria. There is evidence of a Late Eocene and Early Oligocene second paralic phase. This is followed by important Upper Oligocene to Lower Miocene transgressions. The Upper Miocene was a period of regression and faulting. The Lower Pliocene transgression which followed was more extensive in Western Victoria than in South Australia.

CONDITIONS OF TERTIARY SEDIMENTATION IN SOUTHERN AUSTRALIA

By MARTIN F. GLAESSNER *

[Read 13 November 1952]

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SUMMARY

Tertiary sedimentation in southern Australia begins generally with paralic deposits (brackish, lignitiferous, intermittently marine), followed in some areas by an Upper Eocene marine ingression. This is widespread in South Australia, possibly extending to Western Australia, but limited in Victoria. There is evidence of a Late Eocene and Early Oligocene second paralic phase. This is followed by important Upper Oligocene to Lower Miocene transgressions. The Upper Miocene was a period of regression and faulting. The Lower Pliocene transgression which followed was more extensive in Western Victoria than in South Australia.

INTRODUCTION

Until recently it was thought that the sequence of Tertiary strata throughout South Australia and the Murray Basin consisted of a lignitic, largely terrestrial formation of Oligocene age at the base, followed by Miocene, mostly in polyzoal limestone facies, overlain with slight local unconformity by Lower or Upper Pliocene sands or shell beds. The fallacy of this interpretation was first demonstrated by Parr who found *Hantkenina* of Upper Eocene age together with other significant elements of the *Hantkenina*-fauna described by him previously from the Otway coast in Victoria, in what was then believed to be the base of the marine Miocene at Aldinga Bay. Unfortunately, Parr died before he could complete his investigations and publish the results. In 1950 it was decided by the writer, in consultation with Professor Sir Douglas Mawson who had advocated, initiated and sponsored palaeontological investigations in the critical areas for many years, to make the stratigraphy and palaeontology of the Tertiary deposits of South Australia and adjoining areas the subject of a major research project. Its first stage was to be the detailed mapping of critical sections so that samples for micropalaeontological investigation and specimens of the megascopic fauna could be taken from strictly defined horizons and so their exact stratigraphic ranges determined. This was to be supplemented by a similarly detailed study of well-selected samples from deep bores which were very generously made available by the South Australian Mines Department to the writer in his capacity as Honorary Consultant to the Department. Concurrently a critical systematic study of significant fossils from these sections was to be undertaken in order to give a clearly defined meaning and status to names of fossils found to be of importance in these studies. This work is being carried out by research students at the University of Adelaide, under the writer's direction, with financial assistance from the University's research funds. It is desirable to accompany with a progress report on the whole project the publication of the first paper describing results of this work (Reynolds 1953). As stratigraphic field work must precede descriptive palaeontological studies in order to base selection of samples and species for description on known field relations, more precise palaeontological age determinations will constitute the final rather than the initial stage of the project. The present progress report deals therefore with the nature of the deposits in their observed sequence rather than with their exact ages.

* University of Adelaide.

EARLY EOCENE PARALIC FACIES

The term paralic (for a recent definition see Tercier 1939, p. 88) denotes sedimentation in a changing and alternating marine and non-marine environment of coastal swamps, lagoons, estuaries or deltas. In the Aldinga Bay section Tertiary sedimentation commences with the non-marine North Maslin Sands. These sands which contain a flora thought by Chapman (1935) to be Lower Oligocene, are well below the *Hantkenina* zone and are therefore not likely to be younger than early Eocene. The overlying South Maslin Sands which are glauconitic and at least intermittently marine are regarded by Reynolds as formed in the marine part of a delta. Both formations appear in the adjacent section at Christie's Beach and on their boundary laterilization indicating emergence is noticeable. This section was mapped and will be described by Miss M. Wade. Recent studies by B. Daily indicate that the Noarlunga lignites correspond to the North Maslin Sands and a deep bore in the Willunga Basin which is now under examination has also reached lignitic sands below a bed with *Hantkenina*.

In Victoria, the *Hantkenina*-fauna occurs in the Cape Otway area (Aire Coast). Recent field investigations by Raggatt and Crespin (1952) have led to the conclusion that equivalents of the "Anglesean" are found below the *Hantkenina*-zone of Brown's Creek instead of above as previously assumed (and as shown in Glaessner 1951, p. 274); that the "Anglesean" east of the Otways (now named Demon's Bluff Formation) overlies the "unfossiliferous" Boonah Sandstones and the Eastern View Coal Measures; and that the equivalents of that Formation west of the Otways overlie the Pebble Point Beds and thus are part of the Wangerrip Formation. Baker (1950) described the Wangerrip Formation as "littoral, shallow water deposits, such as conglomerates, coarse grits, sandstones (some gritty, some carbonaceous and some iron stained) and ironstones that are overlain by, and in part interbedded with, clays containing gypsum and copiapite." Fossils occur only in bands and lenses and some of these beds contain only carbonaceous material and fragments of wood.

The fauna of the Pebble Point Beds indicates early Eocene (or possibly Paleocene) age. It was found recently in similar strata near Casterton, 120 miles northwest of the first locality (Kenley 1952). It is likely that at least some of these deposits are time equivalents of the pre-Upper Eocene paralic strata of South Australia though there is no direct palaeontological evidence for their correlation. The poor fauna and peculiar lithology of the Anglesea and Addiscot Members of the Demon's Bluff Formation indicate paralic environment.

LATE EOCENE MARINE FACIES AND EQUIVALENTS

The South Maslin Sand is overlain with a slight erosional disconformity by the Tortachilla Limestone which grades upward into the "transitional" basal beds of the Blanche Point Marl with *Hantkenina alabamensis compressa* Parr and other Eocene fossils. Particularly important restricted species of the Tortachilla fauna are *Australanthus longianus* (Gregory) and *Aturia clarkei attenuata* Teichert and Cotton. *Notostrea lubra* Finlay occurs abundantly in the basal bed of the "Banded Marl" Member of the Blanche Point Marls, where siliceous sponges also become abundant and conspicuous. This distinctive shallow-water marine interval is equally well developed in the Willunga and Noarlunga Basins. Foraminiferal species such as *Asterigerina adelaidensis* (Howchin) which occur in it permit us to trace it into the Adelaide Basin, where this species was first described (as *Truncatulina margaritifera* var. *adelaidensis*) from 195-218 ft. in the Kent Town bore (Howchin 1891). It also occurs in the Croydon bore at

1,681 ft. This correlation explains the much-discussed difference in thickness between the pre-Pliocene fossiliferous sediments in the Kent Town and Croydon bores (which are separated by the Para Fault) as the result of pre-Pliocene erosion of at least 800 feet of strata from the upthrow side of the fault.

The Late Eocene marine formation is apparently also represented at Kingscote, Kangaroo Island, where *Australanthus longianus* occurs and in the lower Nullarbor (Eucla) limestones where D. King collected *Notostrea lubra* and *Australanthus longianus* (see King 1950; specimens in the collection of the Geology Department, University of Adelaide). It is suggested that the Plantagenet Beds of Western Australia, with *Aturia clarkei* Teichert and a rich fauna of sponges are probably about the same age. They had been placed in the Miocene by Chapman and Crespin (1934). The first discovery of Eocene in Australia (apart from the tropical and Indo-Pacific faunas of the North-west) was the result of Parr's brilliant analysis of the fauna of small foraminifera from the King's Park bore in Perth (1938). This was followed by Parr's discovery of *Hantkenina alabamensis compressa* in the Otways area (Parr 1947). Since then, Raggatt and Crespin (1952) have announced in a preliminary note "the discovery of *Hantkenina alabamensis* at the top of the Jan Juc Formation at Bird Rock", the type locality of the Janjukian. The writer is not prepared to accept this statement as evidence of Upper Eocene age of the Janjukian (as restricted by Raggatt and Crespin) because a critical study of a considerable number of samples from the same locality has shown that the foraminiferal assemblage differs significantly from that of the other known Eocene localities with *Hantkenina alabamensis compressa*. No further specimens of this species or of other restricted species usually associated with it have been found at Bird Rock. The composition of the fauna suggests a younger age than the *Hantkenina* faunal zone. Whether this anomalous reported occurrence indicates that the biozone of this *Hantkenina* extended beyond the *Hantkenina* faunal zone (and beyond the limits of the biozone of the genus elsewhere), whether the specimens are derived from older strata, or whether some other explanation is possible cannot be decided until the faunas are described. The typical Brown's Creek fauna has not been found east of the Otways.

LATE EOCENE AND EARLY OLIGOCENE PARALIC FACIES

In the Maslin Bay-Aldinga Bay standard section the "Banded Marl" Member of the Blanche Point Formation grades upward into the "Soft Marl" Member. Both together represent the well-known *Turritella* beds. Their upper part was described by Tate in his account of the Croydon bore as "bituminous" and Reynolds mentions in his description of Aldinga Bay their dark colour which "may be due partly to the presence of organic matter." There is evidence from bores in the Willunga Basin, which is being examined by G. Woodard, of the association of lignites with *Turritella* marls above *Hantkenina*-bearing beds. Reynolds describes the Chinaman's Gully Beds as a thin non-marine formation overlying the Blanche Point "Soft Marls." They occur in a corresponding position in the Noarlunga basin at the mouth of the Onkaparinga River. This evidence indicates the existence, above the Upper Eocene marine sediments, of another group of paralic deposits. Faunal studies are not sufficiently advanced to place exactly the boundary between Eocene and Oligocene in relation to these deposits and indeed it is questionable whether this boundary can be fixed by objective criteria in the absence of such world-wide markers as *Discocyclina* or *Nummulites*. As these paralic sediments are well above the *Hantkenina* beds and are overlain by a thick marine formation grading upwards into Lower Miocene, they are likely to represent the lower part of the Oligocene. The discovery of a second paralic

phase of probably early Oligocene age in South Australia suggests that where the *Hantkenina* fauna is absent, the paralic facies may extend from the early Eocene to the early Oligocene. Raggatt and Crespin (1952, p. 143) recognised erosional disconformities between the Angahook Member of the Demon's Bluff Formation and the Jan Juc Formation but considered their time significance as small. At Airey's Inlet the erosional interval between the basalts of the Angahook Member and the overlying Torquay Group is obvious. The "ligneous sands and clays" of Dartmoor which are overlain by "Janjukian with *Victoriella*" (Gloe 1947) should be carefully examined for evidence which may prove whether they represent the early Eocene or the early Oligocene or both paralic phases. Their equivalents in the south-east of South Australia are now being examined from this point of view.

LATE OLIGOCENE AND LOWER MIOCENE MARINE FACIES

The upper paralic deposits of the Willunga Basin and their equivalents in the Noarlunga Basin are overlain by polyzoal limestones and calcareous sands (calcarenites). Their fauna of mollusca, echinoids and foraminifera differs strikingly from that of the Tortachilla polyzoal limestones and their equivalents. The polyzoal Port Willunga Beds reach thicknesses of nearly 300 feet in the Willunga Basin and over 400 feet in the Adelaide Basin (Croydon bore). In the Myponga Basin these polyzoal limestones and interbedded sandy clays are also about 400 feet thick, as proved by the Myponga bore which is being examined by Miss M. Wade. A Lower Miocene *Lepidocyclina* fauna corresponding to that of the Batesford Limestone was found in a sample from the upper third of this formation. In the Willunga Basin the lower part of the Port Willunga Beds contains *Sherbornina* and *Gümbelina* and in the Adelaide Basin (Miles 1952) Miss Crespin found the *Sherbornina*-fauna overlain by the Lower Miocene *Austrotrillina*-fauna. These beds represent the Upper Oligocene and Lower Miocene. The Port Willunga beds resemble in lithology and fauna the Gambier Limestone and also the Torquay Group (Janjukian *sensu lato*). This has been observed also by earlier authors. In South Australia, disconformable or unconformable relations seem to be the rule at the base of these marine deposits. In the Willunga and Noarlunga Basins they rest on non-marine sediments. South of Sellick's Beach they overlie transgressively with a basal breccia the Cambrian strata of the Willunga scarp. This is, therefore, basically not a Late or post-Tertiary fault scarp but an old shoreline, probably representing an earlier fault-line scarp, over which the Oligocene sea transgressed. In Late Tertiary (possibly Late Miocene) time a steep flexure developed over it, as described by Howchin (1911). In the Myponga basin the same polyzoal limestones rest on pre-Cambrian and on the overlying Permian glacial deposits. On the eastern flank of the Mount Lofty Ranges post-eocene Tertiary limestones overlie granites or slates from which they are locally separated (near Strathalbyn) by a thin pebble bed. I am indebted to Mr. R. C. Sprigg, of the South Australian Mines Department, for an opportunity to study Knight's Quarry, six miles north-east of Mt. Gambier where the Gambier polyzoal limestone overlies a non-marine formation with angular unconformity. The base of the limestone is marked here by a nodule bed. Such unconformable relations at the base of the Upper Oligocene to Lower Miocene marine deposits seem to be of regional importance. In the Nullarbor Plains the Lower Miocene limestone with *Austrotrillina* rests on a paralic sequence of Lower Tertiary strata near Pidinga (King 1950) but apparently it overlies directly the Eocene limestones in the caves described earlier by King (1951). In Victoria, Baker (1944) found a nodule bed containing derived Eocene fossils near the mouth of the Gellibrand River, forming the

base of beds with "Janjukian" foraminifera grading upwards into Lower Miocene ("Batesfordian") with *Orbulina*. This Late Oligocene and Lower Miocene transgression was apparently not strictly contemporaneous throughout southern Australia and its base should not be taken as a time-stratigraphic horizon. The underlying Lower Tertiary sediments are not everywhere of the same age. The transgression was preceded in some areas by uplift and erosion while in others there is no evidence of earlier open sea sedimentation. In particular, the Late Eocene marine sediments do not appear to have extended over the Mount Lofty Ranges and in the Torquay-Port Phillip area the early Tertiary paralic sedimentation was not interrupted by pronounced marine phases.

LATE TERTIARY SEDIMENTATION

The Late Miocene seems to have been a period of regression, uplift and faulting. Its sediments are not known in South Australia. From Adelaide to Sellick's Beach the Pre-Cambrian and Permian, and the various members of the Tertiary sequence, are unconformably overlain by Pliocene sands, clays and limestones. Along a narrow coastal fringe these are intermittently fossiliferous but similar unfossiliferous and probably non-marine sediments extend a few miles inland. As the Pliocene strata are about 300 feet thick in the Adelaide Basin they cannot be expected to be confined to a thin layer at a constant level on the faulted blocks south of Adelaide. Similar deposits, some of them fossiliferous, are indeed found up to 300 feet above sea level and there seems to be no good reason to consider them as post-Pliocene on account of their elevated position as has been suggested.

In Western Victoria Lower Pliocene ("Kalimnan") marine faunas are known from Hamilton and from bores in the Mallee and Wimmera. The Pliocene strata seem to rest on Lower Miocene or older deposits. Late and Post-Tertiary erosion has removed the early Pliocene from the coastal areas.

CONCLUSION

A large part of southern Australia was during Tertiary time a "mobile shelf" area. Conglomerates are generally confined to the earliest and latest stages of sedimentation, other sediments are dominantly fine-grained and detrital, with polyzoal limestones widely developed at times of widespread transgression. There is evidence of two paralic and two marine periods (as shown by Reynolds in the Maslin Bay-Aldinga Bay section). Intermittently marine and brackish or lignitic strata may therefore be followed either by late Eocene or by late Oligocene to Miocene marine deposits.

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ROYAL SOCIETY OF SOUTH AUSTRALIA (INCORPORATED)

Receipts and Payments for the Year ended 30th September, 1952

RECEIPTS

	£	s.	d.
To Balance 1st October, 1951	335	6	3
„ Subscriptions	163	2	3
„ Government Grant for Printing, etc.	1000	0	0
„ Sale of Publications and Reprints....	87	16	6
„ Hire of Rooms	6	6	0
„ Interest	213	17	4
	£1,806	8	4

PAYMENTS

	£	s.	d.	£	s.	d.
By Transactions (Printing and Publishing, Vol. 74, Pt. 1 and 2)				662	4	3
„ Reprints				17	12	6
„ Binding Volumes				256	7	2
„ Librarian				43	1	0
„ Printing, etc.				46	2	6
„ Postages				45	0	0
„ Sundries:—						
Lighting	11	17	8			
Insurance	0	7	6			
Cleaning Rooms	39	11	0			
Hire Epidiascope	3	11	0			
Petties	2	7	11	57	15	1
„ Balances—30th Sept., 1952:—						
Australian and N.Z. Bank Ltd.	145	12	4			
Savings Bank of S.A.	532	13	6	678	5	10
				£1,806	8	4

Audited and found correct. The Stock and Bank Balances have been verified by certificates from the respective institutions.

F. M. ANGEL
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R. V. SOUTHCOTT, M.B., B.S.
Hon. Treasurer

ENDOWMENT FUND as at 30th September, 1952

	£	s.	d.	£	s.	d.
1951—October 1						
To Balance—						
Aust. Inscribed Stock ..	6,010	0	0			
Savings Bank of S.A.....	62	18	7	6,072	18	7
1952—September 30						
To Interest—:						
„ I Inscribed Stock	202	2	7			
Savings Bank of S.A...	11	14	9	213	17	4
				£6,286	15	11

	£	s.	d.	£	s.	d.
1952—September 30						
By Revenue Account				213	17	4
„ Balance:—						
Aust. Inscribed Stock ..	6,010	0	0			
Savings Bank of S.A. ..	62	18	7	6,072	18	7
				£6,286	15	11

Audited and found correct. The Stock and Bank Balances have been veried by certificates from the respective institutions.

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Hon. Treasurer

Adelaide, 7th October, 1952

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1945 Cecil T. Madigan, M.A., B.E., D.Sc., F.G.S.
1946 Herbert M. Hale

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AS AT 30 MARCH 1951

Those marked with an asterisk (*) have contributed papers published in the Society's Transactions. Those marked with a dagger (†) are Life Members.

Any change in address or any other changes should be notified to the Secretary.

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1949. *Cleland, Prof. J. B., M.D., Dashwood Road, Beaumont, S.A.—*Fellow,* 1895-1949; *Verco Medal,* 1933; *Council,* 1921-26, 1932-37; *President,* 1927-28; 1940-41; *Vice-President,* 1926-27, 1941-42.

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1951. Andrews, J., M.B., B.S., 40 Seafield Avenue, Kingswood, S.A.
1935. *Andrewartha, H. G., M.Agr.Sc., D.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council,* 1950; *Vice-President,* 1950-51; *President,* 1951-.
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1932. Begg, P. R., D.D.Sc., L.D.S., Shell House, 170 North Terrace, Adelaide.
1928. Best, R. J., D.Sc., F.A.C.I., Waite Institute (Private Mail Bag), Adelaide.
1953. Bird, A. F., B.Sc., Zoology Department, University, Adelaide.
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1923. Burdon, R. S., D.Sc., University of Adelaide—*Council,* 1946.

Date of Election.

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1951. CHITTLEBOROUGH, R. G., B.Sc., c/o C.S.I.R.O., Div. of Fisheries, 1 Museum Street, Perth, W.A.
1929. CHRISTIE, W., M.B., B.S., Education Department, Social Services, 51 Pirie Street Adelaide—*Treasurer*, 1933-38.
1950. COALSTAD, S. E., B.Sc., 6 Hampton Street, Hawthorn, S.A.
1949. COLLIVER, F. S., Geology Department, University of Queensland.
1930. *COLQUHOUN, T. T., M.Sc., 10 French Street, Netherby, S.A.—*Secretary*, 1942-43.
1907. *COOKE, W. T., D.Sc., A.A.C.I., 4 South Terrace, Kensington Gardens, S.A.—*Council*, 1938-41; *Vice-President*, 1941-42, 1943-44; *President*, 1942-43.
1942. *COOPER, H. M., 51 Hastings Street, Glenelg, S.A.
1929. *COTTON, B. C., S.A. Museum, Adelaide—*Council*, 1943-46, 1948-49; *Vice-President*, 1949-50, 1951; *President*, 1950-51.
1953. DANE, D. M. S., M.B., B.Chir., M.R.C.S., L.R.C.P., B.A., Institute of Medical and Veterinary Science, Frome Road, Adelaide.
1951. DAVIDSON, A. C. L., Ph.D., B.Sc., Waite Research Institute, Private Mail Bag, G.P.O., Adelaide.
1950. DELAND, C. M., M.B., B.S., D.P.H., D.J.M., 29 Gilbert Street, Goodwood, S.A.
1941. DICKINSON, S. B., M.Sc., 52 Burnside Road, Kensington.—*Council*, 1949-51; *Vice-President*, 1951-.
1930. DIX, E. V., Hospitals Department, Rundle Street, Adelaide, S.A.
1944. DUNSTONE, S. M. L., M.B., B.S., 124 Payneham Road, St. Peters, Adelaide.
1931. DWYER, J. M., M.B., B.S., 105 Port Road, Hindmarsh, S.A.
1933. *EARDLEY, MISS C. M., M.Sc., University of Adelaide—*Council*, 1943-46.
1945. *EDMONDS, S. J., B.A., M.Sc., Zoology Department, University, Adelaide.
1902. *EDQUIST, A. G., 19 Farrell Street, Glenelg, S.A.—*Council*, 1949-.
1944. FERRES, MISS H. M., M.Sc., 8 Taylor's Road, Mitcham, S.A.
1927. *FINLAYSON, H. H., 305 Ward Street, North Adelaide—*Council*, 1937-40.
1951. FISHER, R. H., 265 Goodwood Road, Kings Park, S.A.
1923. *FRY, H. K., D.S.O., M.D., B.S., B.Sc., F.R.A.C.P., Town Hall, Adelaide—*Council*, 1933-37; *Vice-President*, 1937-38, 1939-40; *President*, 1938-39.
1951. FULTON, COL. D., C.M.G., C.B.E., Aldgate, S.A.
1932. *GIBSON, E. S. H., M.Sc., 297 Cross Roads, Clarence Gardens, Adelaide.
1927. GODFREY, F. K., Box 951H, G.P.O., Adelaide.
1935. †GOLDSACK, H., Coromandel Valley, S.A.
1925. †GOSSE, SIR JAMES H., Gilbert House, Gilbert Place, Adelaide.
1910. *GRANT, PROF. SIR KERR, M.Sc., F.I.P., 56 Fourth Avenue, St. Peters, S.A.
1930. GRAY, J. T., Orroroo, S.A.
1933. GREAVES, H., 12 Edward Street, Glynde, S.A.
1951. GREEN, J. W., 4 Holden Street, Kensington Park, S.A.
1904. GRIFFITH, H. B., Dunrobin Road, Brighton, S.A.
1948. GROSS, G. F., B.Sc., South Australian Museum, Adelaide—*Secretary*, 1950-.
1944. GUPPY, D. J., B.Sc., Mineral Resources Survey, Canberra, A.C.T.
1922. *HALE, H. M., Director S.A. Museum, Adelaide—*Verco Medal*, 1946; *Council*, 1931-34, 1950-; *Vice-President*, 1934-36, 1937-38; *President*, 1936-37; *Treasurer*, 1938-1950.
1949. HALL, D. R., Mern Merna, via Quorn, S.A.
1953. HANSEN, I. V., B.A., 34 Herbert Road, West Croydon, S.A.
1946. *HARDY, MRS. J. E. (nee A. C. Beckwith), M.Sc., Box 62, Smithton, Tas.
1944. HARRIS, J. R., B.Sc., 94 Archer Street, North Adelaide, S.A.
1917. HENDERSON, D. L. W., P.M.B., 20 Bourke, N.S.W.
1944. HERRIOT, R. I., B.Agr.Sc., Soil Conservator, Dept. of Agriculture, S.A.
1951. HOCKING, L. J., 57 Marino Parade, Seacliff, S.A.
1949. HOLLOWAY, B. W., B.Sc., 33 Kyre Avenue, Kingswood, S.A.
1924. *HOSSFELD, P. S., M.Sc., 132 Fisher Street, Fullarton, S.A.
1950. HOWARD, P. F., B.Sc., c/o Great Western Consolidated, Bullfinch, W.A.
1944. HUMBLE, D. S. W., 238 Payneham Road, Payneham, S.A.
1947. HUTTON, J. T., B.Sc., 18 Emily Avenue, Clapham.
1928. IFOULD, P., Kurralta, Burnside, S.A.
1942. JENKINS, C. F. H., Department of Agriculture, St. George's Terrace, Perth, W.A.
1918. *JENNISON, REV. J. C., 7 Frew Street, Fullarton, S.A.
1945. *JESSUP, R. W., M.Sc., 3 Alma Road, Fullarton, S.A.
1910. *JOHNSON, E. A., M.D., M.R.C.S., 1 Baker Street, Glenelg.
1950. JOHNS, R. K., B.Sc., Department of Mines, Flinders Street, Adelaide, S.A.
1951. KALABOVIC, D., B.A.Sc. (Mun.), 22 Grandview Road, Toorak Gardens, S.A.
1951. KESTING, N. G., Dept. Arts and Ed., P.A.C. Preparatory School, 3 Hartley Road, Brighton, S.A.

Date of Election.

1939. †KHAKHAR, H. M., Ph.D., M.B., F.R.G.S., Khakhar Buildings, C.P. Tank Road, Bombay, India.
1949. *KING, D., M.Sc., 44 Angwin Avenue, Blair Athol, S.A.
1933. *KLEEMAN, A. W., M.Sc., University of Adelaide—*Secretary*, 1945-48; *Vice-President*, 1948-49, 1950-51; *President*, 1949-50.
1922. LENDON, G. A., M.D., B.S., F.R.C.P., A.M.P. Building, King William Street, Adelaide.
1948. LOTHIAN, T. R. N., N.D.H. (N.Z.), Director, Botanic Gardens, Adelaide.
1949. LOWER, H. F., 7 Avenue Road, Highgate, S.A.
1931. *LUDBROOK, MRS. W. V. (nee N. H. Woods), M.A., Elimatta Street, Reid, A.C.T.
1948. McCULLOCH, R. N., M.B.E., B.Sc. (Oxon.), B.Agr.Sci. (Syd.), Roseworthy Agricultural College, S.A.
1938. MADDERN, C. B., B.D.S., D.D.Sc., Shell House, North Terrace, Adelaide.
1953. MAELZER, D. A., B.Sc. (Hons.), Waite Institute, Adelaide.
1932. MANN, E. A., C/o Bank of Adelaide, Adelaide.
1939. MARSHALL, T. J., M.Agr.Sc., Ph.D., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1948-.
1905. *MAWSON, PROF. SIR DOUGLAS, O.B.E., D.Sc., B.E., F.R.S., University of Adelaide—*Verco Medal*, 1931; *President*, 1924-25, 1944-45; *Vice-President*, 1923-24, 1925-26; *Council*, 1941-43.
1950. MAY, L. H., B.Sc., 691 Esplanade, Grange, S.A.
1920. MAYO, THE HON. MR. JUSTICE, LL.B., K.C., Supreme Court, Adelaide.
1950. MAYO, G. M. E., B.Ag.Sc., Waite Institute (Private Mail Bag), Adelaide, S.A.
1943. McCARTHY, MISS D. F., B.A., B.Sc., 70 Halton Terrace, Kensington Park.
1953. McCARTNEY, J. E., M.D., D.Sc. (Edin.), Institute of Medical and Veterinary Science, Frome Road, Adelaide.
1945. †*MILES, K. R., D.Sc., F.G.S., Mines Department, Flinders Street, Adelaide.
1951. MILES, J. A. K., M.A., M.B., B.Chir. (Cant.), 48 Gladys Street, Edwardstown, S.A.
1939. MINCHAM, V. H., Hammond, S.A.
1925. †MITCHELL, PROF. SIR W., K.C.M.G., M.A., D.Sc., Fitzroy Ter., Prospect, SA.
1933. MITCHELL, PROF. M. L., M.Sc., University, Adelaide.
1951. MITCHELL, F. J., c/o The South Australian Museum, North Terrace, Adelaide.
1938. MOORHOUSE, F. W., M.Sc., Chief Inspector of Fisheries, Flinders Street, Adelaide.
1936. *MOUNTFORD, C. P., 25 First Avenue, St. Peters, Adelaide.
1944. MURRELL, J. W., Engineering and Water Supply Dept., Port Road, Thebarton, S.A
1944. NEAL-SMITH, C. A., B.Agr.Sci., 16 Gooreen Street, Reid, Canberra, A.C.T.
1944. NINNES, A. R., B.A., 62 Sheffield Street, Malvern, S.A.
1945. *NORTHCOTE, K. H., B.Agr.Sc., A.I.A.S., Waite Institute (Private Mail Bag), Adelaide.
1930. OCKENDEN, G. P., B.A., School House, Box 63, Kimba, S.A.
1947. *OPHEL, I. L., 65 Fifth Avenue, St. Peters, S.A.
1913. *OSBORN, PROF. T. G. B., D.Sc., Department of Botany, Oxford, England—*Council*, 1915-20, 1922-24; *President*, 1925-26; *Vice-President*, 1924-25, 1926-27.
1937. *PARKIN, L. W., M.Sc., c/o North Broken Hill Mining Co., Melbourne, Victoria.
1949. PARKINSON, K. J., B.Sc., 8 Mooreland Avenue, Beverley, S.A.
1945. PATTISON, G., 68 Partridge Street, Glenelg, S.A.
1929. PAULL, A. G., M.A., B.Sc., 10 Milton Avenue, Fullarton, S.A.
1926. *PIPER, C. S., D.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1941-43; *Vice-President*, 1943-45, 1946-47; *President*, 1945-46.
1948. POWRIE, J. K., B.Sc., C.S.I.R.O., Division of Biochemistry, University, Adelaide.
1947. POYNTON, J. O., M.D., M.A., Ch.B., M.R.C.S., L.R.C.P., Institute Medicine, Vet. Science, Frome Road, Adelaide.
1949. PRATTE, R. G., 81 Park Terrace, North Unley, S.A.
1925. *PRESCOTT, PROF. J. A., C.B.E., D.Sc., A.I.C., Waite Institute (Private Mail Bag), Adelaide—*Verco Medal*, 1938; *Council*, 1927-30, 1935-39; *Vice-President*, 1930-32; *President*, 1932-33.
1926. PRICE, A. G., C.M.G., M.A., Litt.D., F.R.G.S., 46 Pennington Terrace, North Adelaide.
1945. PRYOR, L. D., M.Sc., Dip.For., 32 La Perouse Street, Griffith, N.S.W.
1950. *RATTIGAN, J. H., B.Sc., Bureau of Mineral Resources, Melbourne Building, Canberra, A.C.T.
1951. RAYSEN, P., B.Sc., Box 111, Bordertown, S.A.
1944. RICEMAN, D. S., M.Sc., B.Agr.Sc., C.S.I.R.O., Division of Nutrition, Adelaide.
1947. RIEDEL, W. R., B.Sc., Oceanographic Institute, Gottenburg, Sweden.
1948. *RIMES, G. D., B.Sc., 24 Winston Avenue, Clarence Gardens, S.A.
1947. RIX, C. E., 42 Waymouth Avenue, Glandore, S.A.
1946. *ROBINSON, E. G., M.Sc., 42 Riverside Drive, Sudbury, Ontario, Canada.
1953. ROGERS, W. P., Ph.D., Zoology Department, University, Adelaide.
1951. ROSSEL, L. D., c/o High School, Port Pirie, S.A.
1951. ROWE, S. A., 22 Shelley Street, Firle, S.A.
1951. ROWE, S. E., B.Sc., 22 Shelley Street, Firle, S.A.

Date of Election.

1950. Rudd, Prof. E. A., B.Sc., A.M., University, Adelaide, S.A.
1945. Rymill, J. R., Old Penola Estate, Penola, S.A.
1944. *Sandars, Miss D. F., M.Sc., University of Queensland, Brisbane, Queensland.
1950. Saunders, F. L., 79 Winchester Street, Malvern, S.A.
1933. Schneider, M., M.B., B.S., 175 North Ter., Adelaide.
1951. Scott, T. D., B.Sc., c/o S.A. Museum, North Terrace, Adelaide, S.A.
1946. *Segnit, E. R., M.Sc., C.S.I.R.O., Division of Industrial Chemistry, Box 4331, G.P.O, Melbourne, Victoria.
1924. *Segnit, R. W., M.A., B.Sc., Engineering and Water Supply Department, Victoria Square, Adelaide—*Secretary*, 1930-35; *Council*, 1937-38; *Vice-President*, 1938-39, 1940-41; *President*, 1939-40.
1925. *Sheard, H., Port Elliot, S.A.
1936. *Sheard, K., Fisheries Research Div. C.S.I.R.O., University of W.A., Nedlands, W.A.
1945. Shepherd, J. H., M.Sc., B.A., c/o Anglo-Westralian Mining Pty. Ltd.
1934. Shinkfield, R. C., Salisbury, S.A.
1924. Simpson, F. N., Pirie Street, Adelaide.
1949. Simpson, D. A., M.B., B.S., 42 Lockwood Road, Burnside, S.A.
1941. *Smith, T. L., B.Sc., Regional Planning Section, Department of National Development, Canberra, A.C.T.
1941. *Southcott, R. V., M.B., B.S., D.T.M. & H., 13 Jasper Street, Hyde Park, S.A.—*Council*, 1948-51; *Treasurer*, 1951-.
1936. Southwood, A. R., M.D., M.S. (Adel.), M.R.C.P., Wootoona Ter., Glen Osmond, S.A.
1947. *Specht, R. L., M.Sc., 15 Main Road, Richmond, S.A.—*Council*, 1951-.
1936. †*Sprigg, R. C., M.Sc., Mines Department, Flinders Street, Adelaide.
1951. Steadman, Rev. W. R., 1 De Saumarez Street, Kensington Park, S.A.
1947. Spurling, M. B., B.Ag.Sc., Agricultural College, Roseworthy, S.A.
1949. *Spry, A. H., B.Sc., 63 LeFevre Terrace, North Adelaide, S.A.
1938. *Stephens, C. G., D.Sc., Waite Institute (Private Mail Bag), Adelaide.
1935. Strickland, A. G., M.Agr.Sc., 11 Wootoona Terrace, Glen Osmond, S.A.—*Council*, 1947.
1932. Swan, D. C., M.Sc., Waite Institute (Private Mail Bag), Adelaide—*Secretary*, 1940-42; *Vice-President*, 1946-47, 1948-49; *President*, 1947-48.
1948. Swann, F. J. W., 38 Angas Road, Lower Mitcham, S.A.
1951. Swirsei, P., M.Ag.Sc., 22a Henry Street, Croydon, S.A.
1934. Symons, I. G., 35 Murray Street, Lower Mitcham, S.A.—*Editor*, 1947-.
1929. *Taylor, J. K., B.A., M.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1940-43, 1947-50; *Librarian*, 1951-.
1950. Taylor, G. H., B.Sc., Department of Mines, Old Legislative Council Building, North Terrace, Adelaide, S.A.
1948. *Thomas, I. M., M.Sc. (Wales), University, Adelaide—*Secretary*, 1948-50; *Council*, 1950-.
1938. *Thomas, Mrs. I. M. (nee P. M. Mawson), M.Sc., 36 King Street, Brighton.
1940. Thomson, Capt. J. M., 135 Military Road, Semaphore South, S.A.
1923. *Tindale, N. B., B.Sc., South Australian Museum, Adelaide—*Secretary*, 1935-36; *Council*, 1946-47; *Vice-President*, 1947-48, 1949-50; *President*, 1948-49.
1945. Tiver, N. S., M.Sc., B.Agr.Sc., Waite Institute (Private Mail Bag), Adelaide.
1937. *Trumble, Prof. H. C., D.Sc., M.Agr.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1942-1945; *Vice-President*, 1945-46, 1947-48; *President*, 1946-47.
1925. Turner, D. C., Brookman Buildings, Grenfell Street, Adelaide.
1950. Vietch, S. T., Port Lincoln, S.A.
1912. *Ward, L. K., I.S.O., B.A., B.E., D.Sc., 22 Northumberland Avenue, Tusmore—*Council*, 1924-27, 1933-35; *Vice-President*, 1927-28; *President*, 1928-30.
1941. *Wark, D. C., M.Agr.Sc., Div. Plant Industry, C.S.I.R.O., Canberra, A.C.T.
1936. Waterhouse, Miss L. M., 35 King Street, Brighton, S.A.
1953. Waterman, R. A., B.A., M.A., Ph.D., North-western University, Evanston, Illinois, U.S.A.
1939. *Weeding, Rev. B. J., 5 York Street, Henley Beach.
1949. *Wegener, C. F., B.Sc., Department Mines, Flinders Street, Adelaide, S.A.
1946. Whittle, A. W. G., B.Sc., Mines Department, Flinders Street, Adelaide.
1950. Williams, L. D., "Dumosa," Meningie, S.A.
1946. *Wilson, A. F., M.Sc., University of W.A., Nedlands, W.A.
1938. *Wilson, J. O., C.S.I.R.O., Division of Nutrition, Adelaide.
1930. *Womersley, H., F.R.E.S., A.L.S. *(Hon. causa)*, S.A. Museum, Adelaide—*Verco Medal*, 1943; *Secretary*, 1936-37; *Editor*, 1937-43, 1945-47; *President*, 1943-44; *Vice-President*, 1944-45; *Rep. Fauna and Flora Protection Committee*, 1945; *Treasurer*, 1950-51.
1944. *Womersley, H. B. S., M.Sc., University of Adelaide.
1944. Womersley, J. S., B.Sc., Lae, New Guinea.

Date of Election

1923. *WOOD, PROF. J. G., D.Sc., Ph.D., University of Adelaide—*Verco Medal*, 1944; *Council*, 1938-40; *Vice-President*, 1940-41, 1942-43; *Rep. Fauna and Flora Board*, 1940-; *President*, 1941-42; *Council*, 1944-48.

1950. WOODARD, G. D., 20 Kensington Road, Leabrook, S.A.

1953. WOODHOUSE, L. R., 15 Robert Street, North Unley, S.A.

1943. WOODLANDS, HAROLD, Box 989 H, G.P.O., Adelaide.

1945. WORTHLEY, B. W., B.A., M.Sc., A. Inst. P., University, Adelaide.

1948. *WYMOND, A. P., B.Sc., 4 Woodley Road, Glen Osmond, S.A.

1949. YEATES, J. N., L.S., A.M.I.E., A.M.I.M.E., Richards Buildings, 99 Currie Street, Adelaide, S.A.

1944. ZIMMER, W. J., Dip.For., F.L.S. (Lon.), 7 Rupert Street, Footscray West, W.12, Vict.

DECEASED

1944. CASSON, P. B., B.Sc., For. (Adel.), Dip. For., 8 Benjafield Terrace, New Town, Hobart.

1924. DE CRESPIGNY, SIR C. T., F.R.C.P., D.S.O., M.D., 219 North Terrace, Adelaide.

GENERAL INDEX

[Generic and specific names in italics indicate that the forms described are new to science.]

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